Tooth Whitening

An Evidence-Based Perspective

Jorge Perdigão
Editor

Second Edition

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Preface

Dear colleagues,

The first edition of this book was published 7 years ago. Thank you all for the +30,000 visits to download the book chapters and those who purchased the paper edition. All the authors of the second edition hope that you'll enjoy reading this updated edition.

Evidence-based information in Dentistry has become more accessible than ever within the last few years. Unfortunately so has anecdotal evidence with the eruption of social media platforms and the number of users. Opinions posted in social media have quickly become 'evidence' in spite of being at the bottom level of the evidence pyramid. Often students ask me about clinical procedures that they learn on social media.

The bright side is that over the last few years numerous peer-reviewed randomized clinical trials and systematic reviews/meta-analyses have changed some concepts that are still taught in many dental schools. We need to learn and keep adapting our clinical teaching and practice to those evidence-based findings.

Let's keep learning while sharing the 'real' information.

Minneapolis, MN, USA
December 2022

Jorge Perdigão

Acknowledgements

I am forever thankful to all my teachers, mentors, and students. Students have been a great source of inspiration throughout my 37-year academic career.

I also feel blessed to have worked with so many gifted colleagues around the world in clinical and laboratory research. Our readers will also enjoy the outstanding clinical skills of our co-authors that are reflected in this book.

My special appreciation goes to family for their support.

We never quit.

Jorge Perdigão

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Part I

Peroxides for Dental Whitening—History, Mechanism of Action, Side Effects, and Pulp Response

Introduction to Tooth Whitening: Past and Present

1

So Ran Kwon

Abstract

Few dental treatments have been more successful and conservative in nature than tooth whitening. Therefore, it is noteworthy to reflect on the efforts of pioneers in our dental profession that continuously attempted to search for the most effective and safest whitening agent. This quest has extended to determine the best whitening technique to meet our patients' desires and expectations about the esthetic outcome. Here, a short history of tooth whitening agents developed and employed based on the type of discoloration is summarized, as is our current knowledge on the relative efficacy and safety of various types of tooth whitening regimens available. The information on proper diagnosis and treatment planning will guide the clinician in establishing a step-by-step protocol for determining the etiology of the discoloration, selecting the best whitening technique, and monitoring tooth color until the desired outcome has been achieved.

1.1 History of Tooth Whitening

Tooth whitening is a conservative and effective method to lighten discolored teeth and has been practiced in dentistry for many centuries. During the course of development, careful observation and research on various materials and techniques enabled the dental profession to introduce effective, safe, and predictable methods of whitening.

In the middle 1800s, crowns were commonly used for the treatment of discolored teeth (Kirk 1906). However early pioneers were concerned with the aggressive removal of tooth structure using this technique and found tooth whitening to be a

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promising alternative (Kirk 1906). Despite the great plea for preservation of tooth structure and less invasive dentistry, the majority of practitioners opposed tooth whitening and argued that it was technique sensitive, the duration of treatment was too long, and the relapse of color to the original shade was too frequent (Kirk 1889). Nevertheless, the quest for the ideal whitening material continued and resulted in numerous experimental whitening agents, which were either direct or indirect oxidizers employed mostly for the treatment of non-vital teeth (Kirk 1889). A variety of whitening agents were used, reflecting the diverse nature of discoloration. For example, oxalic acid removed iron stains associated with pulp necrosis and hemorrhage (Atkinson 1862), chlorine was indicated for silver and copper stains encountered with amalgam restorations (Kirk 1889), and ammonia readily removed iodine stains caused by root canal therapy (Stellwagen 1870). The most resistant stains, originating from metallic salts of metallic restorations, were removed using cyanide of potassium, although due to toxicity, its use was not recommended.

While most of the early dental literature focused on non-vital bleaching, as early as 1868, whitening of vital teeth was being attempted with oxalic acid (Latimer 1868). Hydrogen peroxide, currently the most widely used whitening material, was reportedly used in 1884 and was called hydrogen dioxide by Harlan (Harlan 1884). At the time, chemical manufacturing companies were relatively unrestricted, as were dentists, who were at liberty to mix their own solutions in their office (Haywood 1992). Early work also experimented with a variety of ways to speed the bleaching process, including electric current (Westlake 1895), ultraviolet rays (Rosenthal 1911), and other heating instruments and lights (Abbot 1918; Fisher 1911). Manufacturing companies introduced bleaching products in the early 1900s, a transition that limited the choice of materials available to the dental profession (Haywood 1992). The product Superoxol was introduced by a manufacturing company and developed into the bleaching agent used by the majority of dentists because of its efficacy and safety (Haywood 1992).

The introduction of easy and safe to use bleaching agents eventually gave rise to over-the-counter products that could be used at home.

The innovative technique of home whitening can be traced back to the orthodontist, Bill Klusmier, in the late 1960s in Fort Smith, Arkansas (Haywood 1991). While treating a patient during the orthodontic retention phase, he recommended placing Gly-Oxide, an oral antiseptic containing 10% carbamide peroxide (Marion Merrel Dow, Inc.) into the orthodontic positioner at night to facilitate tissue healing (Haywood 1991). He noticed a significant improvement in tissue health and an additional benefit of lightening of tooth color. Further investigation using 10% carbamide peroxide in a custom-made tray worn at night led to the first publication on "Nightguard Vital Bleaching" in 1989 (Haywood and Heymann 1989). This technique caused a major shift from the in-office use of highly concentrated hydrogen peroxide with activating lights to home whitening using lower concentrations of carbamide peroxide. In addition, this technique had fewer side effects and could be offered to a larger section of the general patient population at a lower cost (Haywood 1992).

Since the introduction of nightguard vital home whitening, the formula has been continually improved. Carbopol was added to increase the gel viscosity, so it would stay in the tray longer. This also enabled slow release of the active ingredient, increasing the duration of its effectiveness (Matis et al. 1999). Since some were concerned that whitening gels might cause enamel erosion, various forms of fluoride were added to the formulation. Tooth sensitivity was one of the most common reason patients gave for stopping the whitening process before the desired endpoint, so desensitizers were added, such as potassium nitrate, sodium fluoride, and amorphous calcium phosphate. These additions effectively reduced the incidence and severity of tooth sensitivity (Browning et al. 2008; Gallo et al. 2009; Maghaireh et al. 2014; Navarra et al. 2014; Wang et al. 2015).

As demand for white teeth increased, manufacturers began supplying over-the-counter (OTC) products. The early OTC products were introduced in 1990 and involved a three-step system: an acid prerinse, a lower strength peroxide material, and a final toothpaste. Most often these systems were inappropriately used, causing damage to the enamel (Cubbon and Ore 1991). Strip technology, which involved placing a clear strip of tape with 6.5% hydrogen peroxide onto the tooth (Crest White Strips, Proctor and Gamble), was an innovative advance for home-whitening systems (Gerlach 2000).

Along with tooth whitening material and technique development, the International Organization for Standardization (ISO) created documents that provide requirements and guidelines to ensure that whitening materials and products are fit for their purpose (International Organization for Standardization n.d.). Thus, ISO offers a platform for all stakeholders to join together and create collaborative solutions that yield decisions to improve and support healthcare. The ISO 28399 standard is one of the standards obtained through international consensus for "Products for External Tooth Bleaching" that are used for changing the color of natural teeth toward a lighter or whiter shade. The standard includes test methods for laboratory assessment of tooth bleaching efficacy and was first published in 2011 and revised in 2021. While the "ISO 28399" standard attends to safety aspects, the "ISO/TR 28642" outlines the interpretation of color compatibility results under controlled conditions and methods (International Organization for Standardization 2016). The use of perceptibility (PT) and acceptability thresholds (AT) that are clearly defined for dental materials and human tissues in the technical report has also been adapted as a reference number to determine tooth whitening efficacy (Kwon et al. 2020; Paravina et al. 2019).

The evolution of techniques for tooth whitening is summarized in Table 1.1 and reflects the efforts of the dental profession to preserve tooth structure and simultaneously enhance the restoration and esthetics of smiles. The future will likely bring about even more innovations.

Table 1.1 History of tooth whitening

Date	Name	Material used	Discoloration
1799	Macintosh (Dwinelle 1850)	Invented chloride of lime (called bleaching powder)	
1848	Dwinelle (Dwinelle 1850)	Chloride of lime	Non-vital teeth
1860	Truman (Kirk 1889)	Chloride and acetic acid, Labarraque's solution (liquid chloride of soda)	Non-vital teeth
1861	Woodnut (Woodnut 1861)	Advised placing the bleaching medicament and changing it at subsequent appointments	
1868	Latimer (Latimer 1868)	Oxalic acid	Vital teeth
1877	Chapple (Chapple 1877)	Hydrochloric acid, oxalic acid	All discolorations
1878	Taft (Haywood 1992)	Oxalic acid and calcium hypochlorite	
1884	Harlan (Harlan 1884)	Used the first hydrogen peroxide (called hydrogen dioxide)	All discolorations
1893	Atkinson (Atkinson 1862)	3–25% Pyrozone used as a mouthwash, which also lightened teeth	
1895	Garretson (Haywood 1992)	Applied chlorine to the tooth surface	Non-vital teeth
1910	Prins (Haywood 1992)	Applied 30% hydrogen peroxide to teeth	Non-vital and vital
1916	Kaine (Haywood 1992)	18% hydrochloric acid (muriatic acid) and heat lamp	Fluorosed teeth
1911	Fisher (Fisher 1911)	Reported on the use of hydrogen peroxide with a heating instrument or a light source	Vital teeth
1924	Prinz (Prinz 1924)	First recorded use of a solution of perborate in hydrogen peroxide activated by a light source	Vital teeth
1942	Younger (Haywood 1992)	5 parts of 30% hydrogen peroxide heat lamp, anesthetic	
1958	Pearson (Pearson 1958)	Used 35% hydrogen peroxide inside tooth and also suggested 25% hydrogen peroxide and 75% ether, which was activated by a lamp producing light and heat to release solvent qualities of ether	Non-vital teeth
1961	Spasser (Spasser 1961)	Walking bleach technique: Sodium perborate and water are sealed into the pulp chamber	Non-vital teeth
1965	Bouschor (Bouschor 1965)	5 parts 30% hydrogen peroxide, 5 parts 36% hydrochloric acid, 1 part diethyl ether	Orange colored fluorosis stains
1965	Stewart (Stewart 1965)	Thermocatalytic technique; pellet saturated with Superoxol is inserted into the pulp chamber and heated with a hot instrument	Non-vital teeth

Table 1.1 (continued)

Date	Name	Material used	Discoloration
1966	Mclnnes (Colon Jr and McInnes 1980)	Repeats Bouschor's technique using controlled hydrochloric acid-pumice abrasion	
1967	Nutting and Poe (Nutting and Poe 1967)	Combination walking bleach technique, Superoxol in pulp chamber (30% hydrogen peroxide)	Non-vital teeth
1968	Klusmier (Haywood 1991)	Home bleaching concept started as an incidental finding; Gly-Oxide which contains 10% carbamide peroxide is placed in custom-fitted orthodontic positioner	Vital teeth
1970	Cohen and Parkins (Cohen and Parkins 1970)	35% hydrogen peroxide and a heating instrument	Tetracycline stains
1972	Klusmier (Haywood 1991)	Used the same technique with Proxigel as it was thicker and stayed in the tray longer	Vital teeth
1975	Chandra and Chawla (Chandra and Chawla 1975)	30% hydrogen peroxide, 18% hydrochloric acid flour of Paris	Fluorosis stains
1977	Falkenstein (Haywood 1992)	1-min etch with 30% hydrogen peroxide, 10% hydrochloric acid 100 watt (104 °F) light gun	Tetracycline stains
1979	Compton (Haywood 1992)	30% hydrogen peroxide heat element (130–145 °F)	Tetracycline stains
1979	Harrington and Natkin (Harrington and Natkin 1979)	Reported on external resorption associated with bleaching pulpless teeth	Non-vital teeth
1982	Abou-Rass (Abou-Rass 1982)	Recommended intentional endodontic treatment with internal bleaching	Tetracycline stains
1984	Zaragoza (Zaragoza 1984)	70% hydrogen peroxide and heat for both arches	Vital teeth
1986	Munro (Haywood 1992)	Used Gly-Oxide to control bacterial growth after periodontal root planning Noticed tooth lightening	Vital teeth
1987	Feinman (Feinman 1987)	In-office bleaching using 30% hydrogen peroxide and heat from bleaching light	Vital teeth
1988	Coastal Dental Study Club (Haywood 1992)	Mouth guard bleaching technique	Vital teeth
1988	Munro (Dwinelle 1850)	Presented findings to manufacturer, resulting in first commercial bleaching product: White+Brite (Omni International)	Vital teeth
1989	Croll (Croll 1989)	Microabrasion technique, 10% hydrochloric acid and pumice in a paste	Vital teeth, superficial discoloration, hypocalcification
1989	Haywood and Heymann (Haywood and Heymann 1989)	Nightguard vital bleaching, 10% carbamide peroxide in a tray	All stains, vital and non-vital teeth

(continued)

Table 1.1 (continued)

Date	Name	Material used	Discoloration
1990		Introduction of commercial, over-the-counter bleaching vital teeth products	Vital teeth
1991		Bleaching materials were investigated while the FDA called for all safety studies and data. After 6 months, the ban was lifted	
1991	Numerous authors	Power bleaching, 30% hydrogen peroxide using a light to activate bleach	All stains, vital teeth
1991	Garber and Goldstein (Garber et al. 1991)	Combination of bleaching power and home bleaching	Vital teeth
1991	Hall (Hall 1991)	Recommended no etching teeth before vital bleaching procedure	Vital teeth
1994	American Dental Association (Engel 2011)	Safety and efficacy established for tooth bleaching agents under the ADA seal of approval	
1996	FDA (Times 1996)	FDA approved ion laser technology: argon and CO_2 laser for tooth whitening with patented chemicals	
1996	Reyto (Reyto 1998)	Laser tooth whitening	Vital teeth
1997	Settembrini et al. (Settembrini et al. 1997)	Inside/outside bleaching	Non-vital and vital teeth
1998	Carrillo et al. (Carrillo et al. 1998)	Open pulp chamber, 10% carbamide peroxide in custom tray	Vital
2000	Miara (Miara 2000)	Compressed bleaching technique in patient's own bleaching tray	Vital teeth
2000	Gerlach (Gerlach 2000)	5–10% hydrogen peroxide OTC tooth whitening strips	Vital teeth
2004	Kurthy (Kurthy 2001)	Deep bleaching technique	Vital teeth
2005	Lynch (Lynch 2004)	Ozone whitening using ozone machine	Vital teeth
2006	Kwon (Kwon 2007)	Sealed bleaching: prevents evaporation of active agent by placing a wrap onto the power whitening gel	Vital teeth
2006		Various whitening applications; use of brush applications, pens, and varnish	Vital teeth
2011	ISO 28399 (International Organization for Standardization 2011)	International Standard Organization: dentistry – products for external tooth bleaching	Vital teeth
2016	ISO TR 28642 (International Organization for Standardization 2016)	International Standard Organization: dentistry – guidance on color measurement	Teeth and materials
2021	ISO 28399 (International Organization for Standardization 2021)	International Standard Organization: dentistry – external tooth bleaching products	Vital teeth

Table 1.1 (continued)

Date	Name	Material used	Discoloration
Present		Plasma arc, halogen, UV, LED, and light-activated bleaching techniques Reduction in time with power gels for in-office bleaching, laser-activated bleaching, home bleaching available in different concentrations and with new desensitizers	Vital teeth

Adapted and updated from data in Haywood 1992 (Haywood 1992), with permission from Taylor & Francis Group, LLC

1.2 Current Tooth Whitening Techniques

Tooth whitening is now the most common elective dental procedure (Dutra et al. 2004) and has proven to be safe and effective when supervised by the dentist (American Dental Association Council on Scientific Affairs 2009). More than 1 million Americans whiten their teeth annually, resulting in nearly $600 million in revenues for dental offices (Dutra et al. 2004). Furthermore, improvements in product efficacy achieved through advancements in technology are enabling competitive brands to effectively compete by offering superior product features and therapeutic benefits over the counter. Thus, the global teeth whitening market value for over-the-counter products has been steadily increasing from 2014 to 2019, contributing to the vast majority of the overall teeth whitening market value (Reference Global Teeth Whitening Market Research Report, 2019). Considering the numerous over-the-counter whitening products available and the heightened consumer interest in whiter teeth, it is the responsibility of the dental profession to educate the public about the efficacy and adverse effects of different tooth whitening modalities, suggest or provide appropriate options based on patient's needs and preference, and establish reliable and valid monitoring tools for the whitening process.

The variety of methods and products available reflects the high demand for whiter teeth. Traditionally tooth whitening could be classified into three categories: (1) professionally applied in-office whitening with high-concentration materials (Fig. 1.1a); (2) dentist-dispensed patient-applied home whitening with custom fabricated trays (Fig. 1.1b); and (3) over-the-counter products (Fig. 1.1c), like strips, paint-on gels, or brush-on adhesive liquids (Kwon and Li 2013). With the increased demand and the quest for less expensive options, protocols for do-it-yourself (DIY) whitening (Fig. 1.1d) are now found on the Internet, using natural ingredients such as lemons, apples, and strawberries (Kwon and Li 2013; Natural Teeth Whitening Solutions n.d.). The availability of OTC products and various DIY methods has significantly benefited the general population through better access to whitening. A review on the effectiveness of predominant OTC whitening products showed that compared to whitening dentifrices and paint-on gels, whitening strips were effective in changing tooth color (Naidu et al. 2020). A comparison on the efficacy and erosion potential of whitening strips showed that peroxide-containing whitening strips

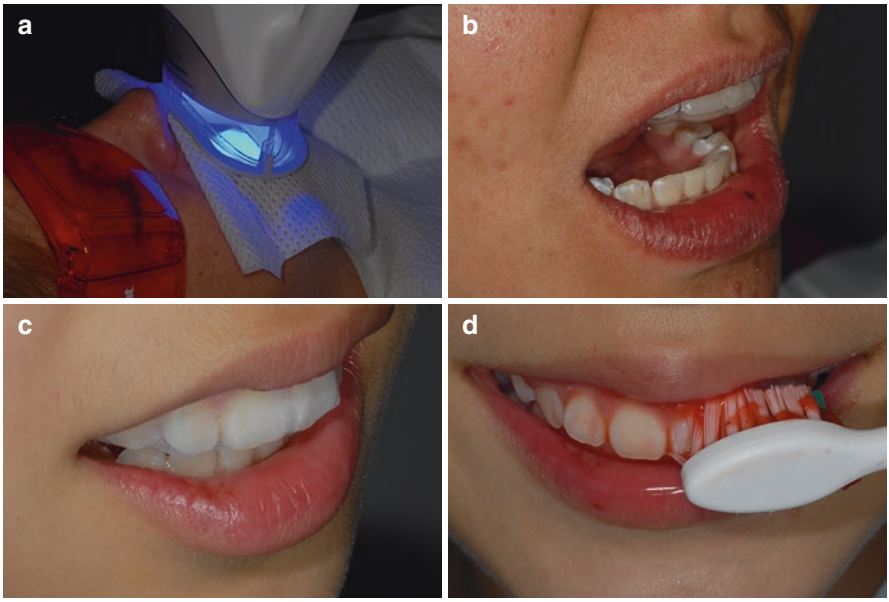

Fig. 1.1 (**a**) In-office whitening procedure with light activation. (**b**) At-home whitening with custom fabricated trays. (**c**) Over-the-counter whitening with strips. (**d**) Do-it-yourself whitening with strawberry puree

had superior whitening efficacy compared to non-peroxide whitening strips while none of the tested whitening strips compromised tooth structure integrity through enamel erosion (Cua et al. 2022). Noteworthy is a systematic review on the effectiveness of whitening strips compared to supervised at-home and in-office whitening. Based on the review, the risk and intensity of tooth sensitivity was lower for whitening strips, while there was no difference in patient satisfaction between the compared whitening modalities. Supervised at-home whitening provided greater color alteration compared to whitening strips when evaluated instrumentally, although the color alteration was undetectable by unaided human eyes (Da Rosa et al. 2020). Despite the proven efficacy of OTC whitening products, teeth whitening without the supervision of a dentist has raised several potential concerns. Tooth discoloration can be the secondary effect of an undiagnosed illness, overuse of whitening materials can damage the enamel surface, and the at-home process goes unmonitored (Kwon and Li 2013; Natural Teeth Whitening Solutions n.d.; Hammel 1998). Therefore, the supervision of a dentist or use of custom fabricated trays should be the treatment modality of choice. The patient's final decision, however, will most likely depend on preference. Although at-home whitening with 10% carbamide peroxide is safe and effective under a dentists' supervision (American Dental Association Council on Scientific Affairs 2009), in-office whitening has its merits, especially in elderly patients who may prefer the convenience and in young children who may require full supervision during the entire procedure. Also, patients that

cannot tolerate wearing trays and those that desire to an immediate effect might also prefer an in-office treatment.

Several studies have compared the efficacy, side effects, and patient acceptance of in-office, at-home, or over-the-counter whitening. Patient opinion was found to depend on the whitening product, study design, application time, and methods of color assessment. One study evaluated the time required to achieve a six-tab difference on a Vita classical shade guide and found this occurred the fastest with in-office whitening, followed by at-home whitening, with over-the-counter whitening requiring the most time (Auschill et al. 2005). The various techniques caused similar levels of gingival or tooth sensitivity, and patients tended to prefer at-home whitening, as previously reported (Bizhang et al. 2009; Da Costa et al. 2010; Giachetti et al. 2010; Serraglio et al. 2016). In vitro studies comparing all four whitening techniques showed in-office, at-home, and over-the-counter whitening produced good results, whereas do-it-yourself whitening with strawberry puree was ineffective (Kwon et al. 2015a; Kwon et al. 2015b). Despite the equivalencies in endpoint whiteness, a concern remains that DIY whitening could reduce tooth microhardness values (Kwon et al. 2015a). A complete summary, including a comparison of the characteristics of current vital tooth whitening technologies, is listed in Table 1.2. It must be noted that this presents an overall comparison of in-office, at-home, and OTC products and techniques containing hydrogen or carbamide peroxide. In anticipation of avoiding harsh chemicals, there has been development and marketing of non-peroxide whitening products that include papain, bromelain, chlorine dioxide, sodium chloride, vinegar, or sodium bicarbonate. Based on a systematic review, the addition of non-peroxide agents into peroxide showed improvement in color change. However, the use of peroxide-free agents alone was not as effective as peroxide-containing whitening agents, warranting more evidence and research on this topic (Ribeiro et al. 2020).

Table 1.2 Summary of current vital tooth whitening techniques

	In-office whitening	At-home whitening	OTC	DIY
Supervision	Yes	Yes	No	No
Active ingredient	HP	HP/CP	HP/Misc	Natural ingredients
Concentration	~up to 40%	~7–35% CP	~up to 12% HP	N/A
Activators	Chemical, LED, laser	Chemical	Chemical, light	N/A
Efficacy	Good	Good	Mod-good	Questionable
Safety	Good	Good	Mod-good	Questionable
Costs	High	Mod	Low	Lowest

Mod moderate, *HP* hydrogen peroxide, *CP* carbamide peroxide

1.3 Diagnosis and Treatment Planning

If a patient desires whiter teeth or would benefit from tooth whitening in conjunction with restorative or orthodontic treatment, the prognosis depends on the nature of the discoloration and the expectations of the patient. Discoloration due to extrinsic origins responds better to whitening, but even discoloration due to intrinsic origin (e.g., tetracycline staining) can respond to whitening if the treatment time is sufficient (Haywood 1991). The absolute contraindications to tooth whitening are few, but unrealistic expectations, an unwillingness to comply with treatment, pregnancy, allergy to components in the whitening material, and severe sensitivity should be carefully considered before starting treatment.

1.3.1 Checklist During Examination

Like any dental examination, the proper steps for diagnosis include obtaining medical and dental history, radiographs, and conducting a thorough clinical examination.

Active dental caries that may be close to the pulp should be given special attention. Carious lesions can be temporarily treated prior to the whitening treatment and finalized once the color is stabilized.

A single dark tooth is a red flag and might be associated with a previous traumatic injury or even a periapical pathosis (Kwon 2011). Radiographs and pulp vitality testing can guide treatment (Chap. 6).

Crack lines are not an absolute contraindication, but the patient should be aware they may exacerbate sensitivity or become even more visible after tooth whitening (Kwon et al. 2009).

Localized decalcification areas and white spots should be carefully examined as they might blend in with the lighter tooth color or could become more noticeable (AlShehri and Kwon 2016). In these instances, other conjunctive treatments, such as microabrasion or resin infiltration, and restorative treatment may be indicated (Chaps. 6, 9, 10, 12, 13, and 15).

Translucent areas often observed on incisal edges will remain translucent upon whitening treatment and may end up looking grayish, continuing to be a concern for some patients. In severe cases, a resin composite restoration to mask the translucency may be needed.

Existing tooth-colored restorations in the esthetic zone should be carefully examined since there may be a need for re-treatment that should be explained in advance, to allow the patient to make the necessary financial commitment.

The symmetry in gingival contour should be observed and possibly resolved prior to whitening, in order to enhance the esthetic outcome.

Severe abrasion, attrition, and recessions should also be observed and explained to the patient, as root exposures will not respond to whitening (Hilton et al. 2013).

Preexisting tooth sensitivity needs to be addressed prior to the treatment, since it may become severe upon treatment compromising the outcome of the treatment (Pashley 1989).

1.3.2 New Challenges in Tooth Whitening

1.3.2.1 Failed Attempts of Tooth Whitening

With the increased interest in tooth whitening, patients currently consult a dental professional about this technique after several failed attempts of trying it on their own (Fig. 1.2). Many have used over-the-counter products in various forms with unsatisfactory results yet exhibit teeth that are already quite light, making the treatment more challenging. Therefore, it is prudent to establish the expectation of the patient and discuss the feasibility of reaching this goal. A very realistic and natural outcome is to reference the white of the eye (Mrazek 2004). However, patients often want teeth that are even whiter, at which point the dentist should carefully discuss the patient's treatment goal, in detail.

1.3.2.2 Erosion

As lifestyles have changed throughout the decades, the consumption of soft drinks has increased in the United States by 300% in 20 years (Calvadini et al. 2000; Lussi et al. 2006). At the same time, the incidence of dental erosion is growing steadily (Lussi et al. 2006). Initially, erosion is limited to the enamel, but in advanced cases, dentin becomes exposed and causes functional and esthetic concerns that require treatment. Generally, the tooth becomes more chromatic with the loss of enamel; and one of the first distinct visual changes patients complain about is tooth color (Fig. 1.3). The treatment plan may vary depending on the severity and location of dental erosion. Restorative options, including direct resin composite and indirect porcelain restorations, are suggested for the rehabilitation of a severe loss of tooth structure. While dental erosion is considered to be a contraindication to tooth whitening (Lussi et al. 2006), it may be beneficial in the early stages if the patient desires a whiter smile. Indeed, since the prevalence of dental erosion is steadily increasing, the topic merits continued research.

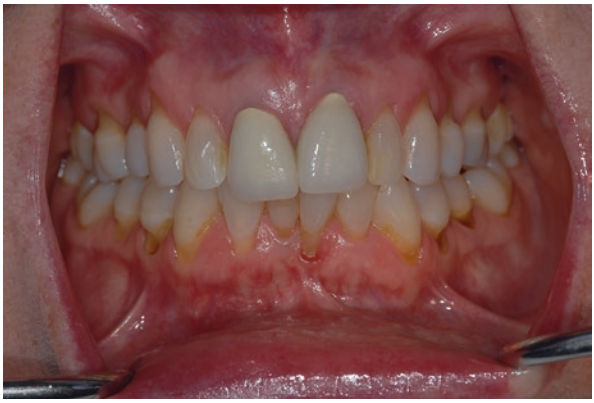

Fig. 1.2 Patient complained about previous failed attempts of tooth whitening. A thorough examination of existing restorations, recessions, abfractions, and gingival asymmetry was followed by a comprehensive treatment plan to satisfy patient's desire for an esthetic outcome

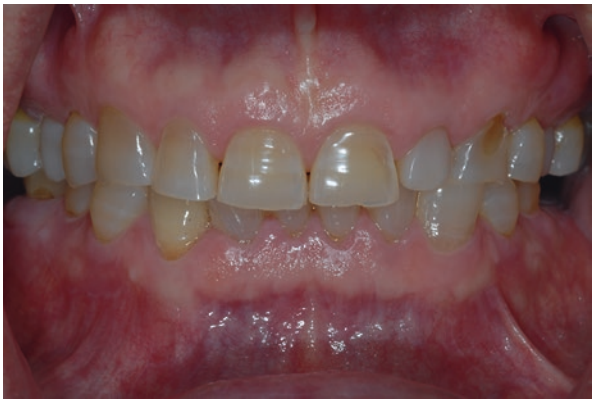

Fig. 1.3 Generalized erosion of teeth can contribute to a more chromatic appearance of teeth

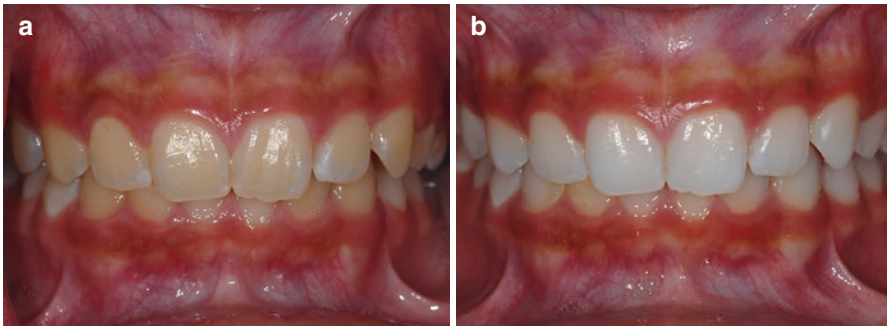

Fig. 1.4 (**a**) The best time for initiating whitening in children should be carefully discussed with the parents. This 12-year-old child complained about his dark teeth as well as the localized white areas on the upper anterior teeth. (**b**) Treatment options include at-home whitening with custom fabricated trays when the child is compliant or in-office whitening where the whole procedure is performed in the clinic

1.3.2.3 Tooth Whitening in Children

Another emerging topic is the age deemed appropriate for tooth whitening (Fig. 1.4a, b). The American Academy on Pediatric Dentistry Council on Clinical Affairs recognized the increased desire for whiter teeth in pediatric and adolescent patients and advised the judicious use of whitening for vital and non-vital teeth, as well as consultation with the dentist to determine the appropriate method and timing for treatment (American Academy on Pediatric Dentistry Council on Clinical Affairs 2015). A single clinical study is currently registered to evaluate the efficacy and tooth sensitivity in an adolescent population (patients ranging from 12 to 20 years) (Pinto et al. 2014).

1.3.2.4 Tooth Whitening on Teeth with Veneers and Orthodontic Braces

Lastly, with the increased interest in cosmetic dentistry, more patients have existing anterior composite resin or porcelain veneers. Over time, teeth become more chromatic, which can shine through existing veneer restorations (Fig. 1.5). To brighten teeth, yet preserve the existing restoration, 10% carbamide peroxide on the lingual surface can be applied with custom trays (Barghi and Morgan 1997; Haywood and Parker 1999). However, the efficacy of whitening through the lingual surface is mainly based on a few clinical cases, and evidence is limited. With the increased awareness for a brighter smile, we face new situations. For example, increasingly patients are requesting tooth whitening while orthodontic braces are in place. A few studies showed tooth whitening with custom fabricated trays over brackets could whiten teeth evenly (Jadad et al. 2011). Nevertheless, more research is needed to address these special and challenging situations to help clinicians in the decision-making process.

1.3.3 Monitoring the Progress of Tooth Whitening

The success of tooth whitening is mainly determined by changes in tooth color and is subjective to each patient; however, evaluating tooth color is extremely difficult because of the complex optical characteristics of the tooth, which include gloss, opacity, transparency, translucency, and optical phenomena such as metamerism, opalescence, and fluorescence (Hunter 1987). Patients commonly inquire about the expected final shade after tooth whitening, so first recording the baseline tooth color will help determine the prognosis and is invaluable in monitoring progress. The prognosis of whitening is significantly enhanced with shades in the yellow-orange range, whereas gray and bluish discolorations are more stubborn (Leonard Jr 2003). Additionally, rather than promising a specific shade, it is prudent to suggest a reliable reference point, such as the white of an eye, so the patient can perceive the

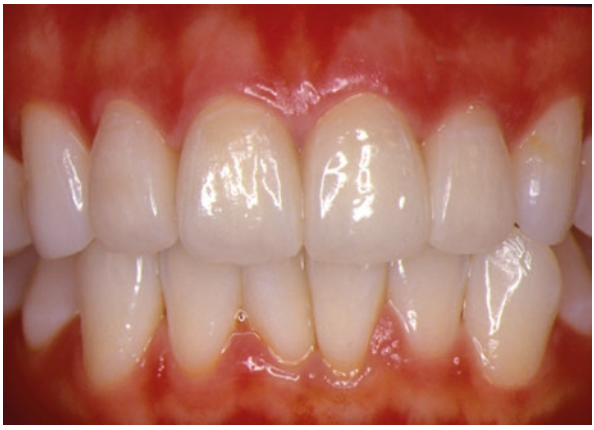

Fig. 1.5 Patient complained about her upper four anterior teeth which had been restored with porcelain laminate veneers. Over time, she noticed a slight darkening of her restored teeth. In this case, whitening from the lingual may reduce the chromaticity of her restored teeth

difference (Mrazek 2004). Commonly the white of the eye is whiter than the baseline tooth color, providing a good reference point for the progress being made during treatment. One of the best ways to demonstrate the efficacy and progress of whitening is to compare the color difference of the upper, treated arch versus the lower, untreated arch. This difference is very helpful in encouraging compliance and also for some who cannot discern color changes well. Many times, it is also important to have color change validated by friends or family, and photographs can be an essential monitoring tool (Kwon and Li 2013).

The Vitapan Classical (VITA Zahnfabrik, Bad Sackingen, Germany) shade guide, with values oriented according from the lightest to the darkest tab, is commonly used for visual shade matching. Nevertheless, the lack of logical order, uniform color distribution, and light shade tabs have been pointed out as drawbacks of the Vitapan Classical (Ontiveros and Paravina 2009). To facilitate the monitoring of tooth whitening, a shade guide was developed, the VITA Bleachedguide 3D Master (VITA Zahnfabrik, Bad Sackingen, Germany), composed of 15 tabs that exhibit a wider color range and more consistent color distribution, compared to the Vitapan Classical. The VITA Bleachedguide 3D Master was also evaluated to be the easiest to arrange, the most harmoniously arranged, and the most preferred for the monitoring of tooth whitening (Paravina 2008). The initial color tab, selected during baseline color measurements, can be easily placed along whitened teeth, leading to the anticipation of the whitening progress. The effect of tooth whitening can be easily monitored by selecting the closest shade tab before and after whitening and counting the difference in tab numbers, expressed as a difference in shade guide units (ΔSGU) (Kwon et al. 2015b).

Methods using specialized instruments to determine tooth shade have become available with advancements in technology. These methods have the advantage of being uninfluenced by the human eye, environment, and light source and generate reproducible results (Chu 2003). Additionally, methods using instruments provide objective shade data and allow different image-analysis options, such as basic shade analysis, smile analysis, and synchronization, to produce a split image of pre- vs. post-whitening. These images (Fig. 1.6a, b) can be printed immediately and are effective tools to show objective results on the progress of tooth whitening. They also provide motivation to initiate and continue treatment. This technique is currently used more often in research, because it is as yet expensive and time-consuming for use in clinical dentistry. Despite the benefit of ruling out subjectivity, the central issue that remains to be addressed is a proper "cutoff" or "threshold" to determine when a whitening material can be considered as effective (Kwon et al. 2020). The "ISO/TR 28642" outlined that color compatibility between dental materials and human tissues presents a very good match if the color difference is at or below $\Delta E^*_{ab} = 1.2$ (perceptibility threshold, PT), while a difference above $\Delta E^*_{ab} = 2.7$ is considered to be an unacceptable match (acceptability threshold, AT) (International Organization for Standardization 2016). A recent study summarized the interpretation of whitening efficacy through PT and AT. Based on the study, a whitening material is deemed not effective when ΔE^*_{ab} is equal or less than 1.2, moderately effective when between 1.2 and 2.7, good when between 2.7 and 5.4, very good

when between 5.4 and 8.1, and excellent when exceeding 8.1 (Paravina et al. 2019). These proposed cutoffs are helpful but warrant future studies and support on a more comprehensive level.

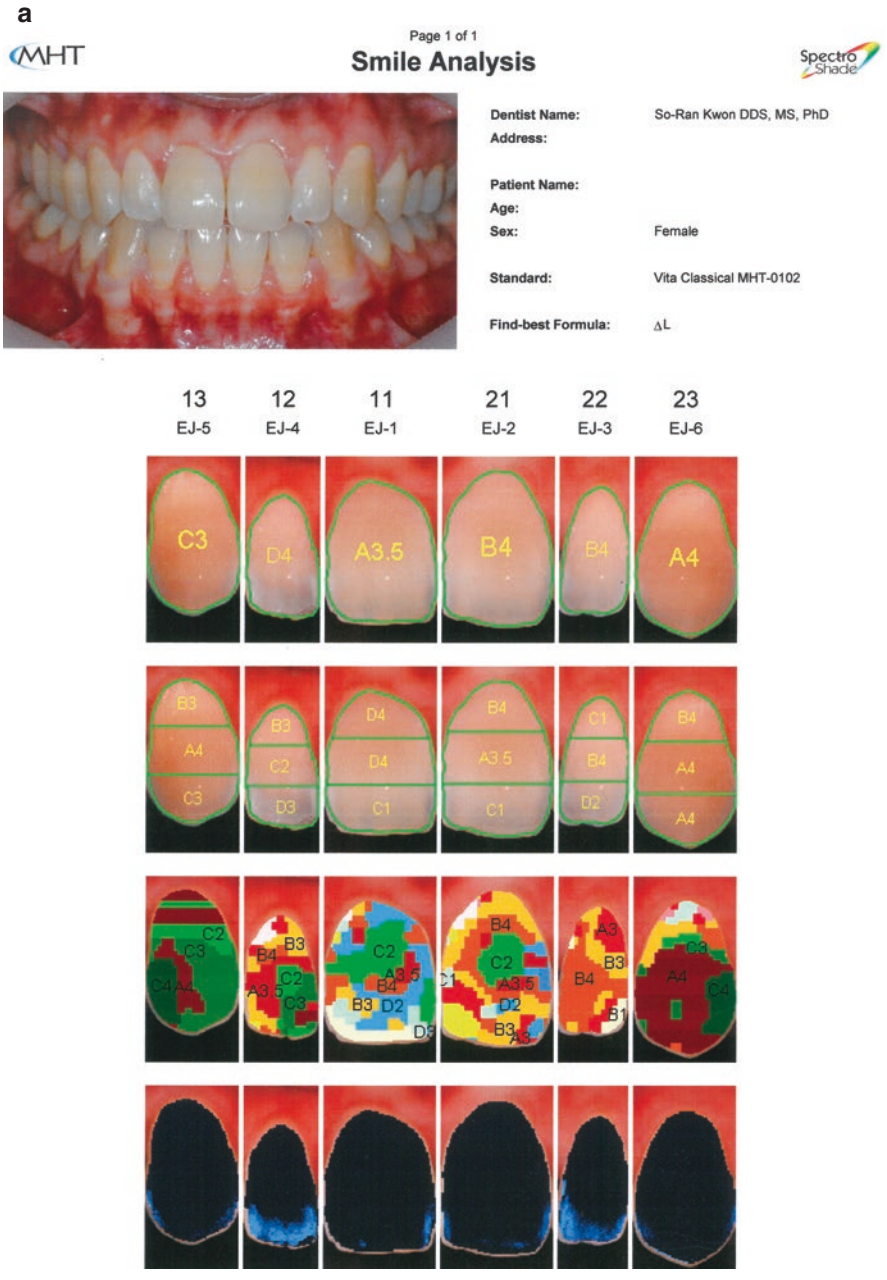

Fig. 1.6 (**a**) Smile analysis before whitening. (**b**) Smile analysis after whitening

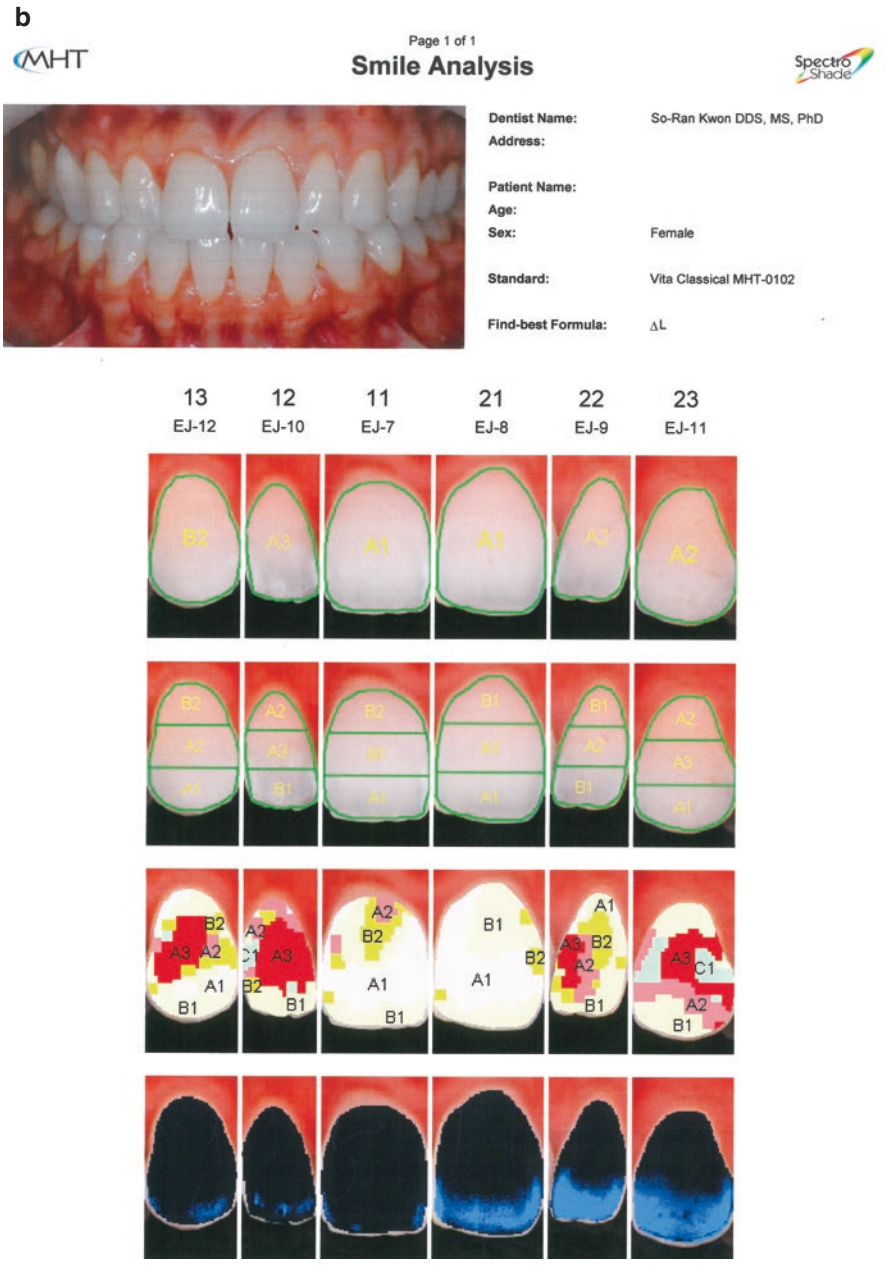

Fig. 1.6 (continued)

Acknowledgment Special thanks go to Taylor & Francis for granting permission to use and update Table 1.2.1 in *Bleaching Techniques in Restorative Dentistry* Edn 1 by Linda Greenwall.

References

Abbot CH (1918) Bleaching discolored teeth by means of 30 per cent perhydrol and the electric light rays. J Allied Dent Soc 13:259
Abou-Rass M (1982) The elimination of tetracycline discoloration by intentional endodontics and internal bleaching. J Endod 8:101–106
AlShehri A, Kwon SR (2016) Managing white spot lesions. Decis Dent 2:18–23
American Academy on Pediatric Dentistry Council on Clinical Affairs (2015) Policy on the use of dental bleaching for child and adolescent patients. Pediatr Dent 37(6 Suppl):76–78
American Dental Association Council on Scientific Affairs (2009) Tooth whitening/bleaching: treatment considerations for dentists and their patients. ADA, Chicago, IL
Atkinson CB (1862) Bleaching teeth, when discolored from loss of vitality: means for preventing their discoloration and ulceration. Dent Cosmos 3:74–77
Auschill TM, Hellwig E, Schmidale S, Sculean A, Arweiler NB (2005) Efficacy, side-effects and patients' acceptance of different bleaching techniques (OTC, in-office, at-home). Oper Dent 30:156–163
Barghi N, Morgan J (1997) Bleaching following porcelain veneers: clinical cases. Am J Dent 10:254–256
Bizhang M, Chun YH, Damerau K, Singh P, Raab WH, Zimmer S (2009) Comparative clinical study of the effectiveness of three different bleaching methods. Oper Dent 34:635–641
Bouschor CF (1965) Bleaching fluorosis stained teeth. N M Dent J 16:33–34
Browning WD, Chan DC, Myers ML, Brackett WW, Brackett MG, Pashley DH (2008) Comparison of traditional and low sensitivity whiteners. Oper Dent 33:379–385
Calvadini C, Siega-Riz AM, Popkin BM (2000) US adolescent food intake trends from 1965 to 1996. Arch Dis Child 83:18–24
Carrillo A, Arredondo Trevino MV, Haywood VB (1998) Simultaneous bleaching of vital teeth and an open-chamber nonvital tooth with 10% carbamide peroxide. Quintessence Int 29:643–648
Chandra S, Chawla TN (1975) Clinical evaluation of the sandpaper disk method for removing fluorosis stains from teeth. J Am Dent Assoc 90:1273–1276
Chapple JA (1877) Hints and queries. Dent. Cosmos 19:499
Chu SJ (2003) Use of a reflectance spectrophotometer in evaluating shade change resulting from tooth-whitening products. J Esthet Restor Dent 15(Suppl 1):S42–S48
Cohen S, Parkins FM (1970) Bleaching tetracycline-stained vital teeth. Oral Surg Oral Med Oral Pathol 29:465–471
Colon PG Jr, McInnes JW (1980) Removing fluorosis stains: reflections of thirty years experience. Quintessence Int Dent Dig 7:61–67
Croll TP (1989) Enamel microabrasion for removal of superficial discoloration. J Esthet Dent 1:14–20
Cua J, Crespo E, Phelps S, Ramirez R, Roque-Torres G, Oyoyo U, Kwon SR (2022) Tooth color change and erosion: hydrogen peroxide versus non-peroxide whitening strips. Oper Dent 47:301–308
Cubbon T, Ore D (1991) Hard tissue and home tooth whiteners. CDS Rev 84:32–35
Da Costa JB, McPharlin R, Paravina RD, Ferracane JL (2010) Comparison of at-home and in-office tooth whitening using a novel shade guide. Oper Dent 35:381–388
Da Rosa G, Maran BM, Schmitt VL, Loguercio AD, Reis A, Naufel FS (2020) Effectiveness of whitening strips use compared with supervised dental bleaching: a systematic review and meta-analysis. Oper Dent 45:E289–E307
Dutra A, Frary J, Wise R (2004) Higher-order needs drive new growth in mature consumer markets. J Bus Strategy 25:26–34
Dwinelle WH (1850) Proceedings of ninth annual meeting of the American Society of Dental Surgeons: discussion of bleaching dead teeth. Am J Dent Sci 1:57–61
Engel D (2011) Update: the ADA seal of acceptance program. J Mich Dent Assoc 93:20
Feinman RA (1987) Bleaching A combination therapy. CDA J 15:10–13

Fisher G (1911) The bleaching of discolored teeth with H2O2. Dent Cosmos 53:246–247
Gallo JR, Burgess JO, Ripps AH, Bell MJ, Mercante DE, Davidson JM (2009) Evaluation of 30% carbamide peroxide at-home bleaching gels with and without potassium nitrate-a pilot study. Quintessence Int 40:e1–e6
Garber DA, Goldstein RE, Goldstein GE, Schwartz CG (1991) Dentist monitored bleaching: a combined approach. Pract Periodontics Aesthet Dent 3:22–26
Gerlach RW (2000) Shifting paradigms in whitening: introduction of a novel system for vital tooth bleaching. Compend Contin Educ Dent Suppl 29:S4–S9
Giachetti L, Bertini F, Bambi C, Nieri M, Scaminaci Russo D (2010) A randomized clinical trial comparing at-home and in-office whitening techniques: a nine-month follow-up. J Am Dent Assoc 141:1357–1364
Global Teeth Whitening Market Research Report (2019) Segment by major players, types, applications and regions, 2014–2024. Maia Research Analysis
Hall DA (1991) Should etching be performed as a part of a vital bleaching technique? Quintessence Int 22:679–686
Hammel S (1998) Do-it-yourself tooth whitening is risky US News and World Report 2:66
Harlan AW (1884) The removal of stain from the teeth caused by administration of medicinal agents and the bleaching of pulpless teeth. Am J Dent Sci 20:1884–1885
Harrington GW, Natkin E (1979) External resorption associated with bleaching of pulpless teeth. J Endod 5:344–348
Haywood VB (1991) Overview and status of mouthguard bleaching. J Esthet Dent 3:157–161
Haywood VB (1992) History, safety, and effectiveness of current bleaching techniques and applications of the nightguard vital bleaching technique. Quint Int 23:471–488
Haywood VB, Heymann HO (1989) Nightguard vital bleaching. Quintessence Int 20:173–176
Haywood VB, Parker MH (1999) Nightguard vital bleaching beneath existing porcelain veneers: a case report. Quintessence Int 30:743–747
Hilton TJ, Ferracane JL, Broome JC (2013) Summitt's fundamentals of operative dentistry, 4th edn. Quintessence Pub Co. Inc., Batavia, IL, p 417
Hunter RS (1987) The measurement of appearance, 2nd edn. John Wiley and Sons, Inc, New York
International Organization for Standardization (2011) ISO 28399 Dentistry–Products for external tooth bleaching. International Organization for Standardization, Geneva
International Organization for Standardization (2016) ISO TR 28642 Dentistry–Guidance on colour measurement. International Organization for Standardization, Geneva
International Organization for Standardization (2021) ISO 28399 Dentistry–External tooth bleaching products. International Organization for Standardization, Geneva
International Organization for Standardization. n.d. ISO: What we do. https://www.iso.org/what-we-do.html. Accessed 25 Sept 2022
Jadad E, Montoya J, Arana G, Gordillo LA, Palo RM, Loguercio AD (2011) Spectrophotometric evaluation of color alterations with a new dental bleaching product in patients wearing orthodontic appliances. Am J Orthod Dentofac Orthop 140:e43–e47
Kirk EC (1889) The chemical bleaching of teeth. Dent Cosmos 31:273–283
Kirk EC (1906) Chemical principles involved in tooth discoloration. Dent Cosmos 48:947–954
Kurthy R (2001) Improve your bleaching results with bleaching trays that fit. Dent Today 20:68–70
Kwon SR (2007) The sealed bleaching technique. Aesthet Dent Today 5:18–22
Kwon SR (2011) Whitening the single discolored tooth. Dent Clin N Am 55:229–239
Kwon SR, Li Y (2013) Ensure the success of tooth whitening: how to effectively monitor color change during the bleaching process. Dimen Dent Hyg 11:52–55
Kwon SR, Ko S, Greenwall L (2009) Tooth whitening in esthetic dentistry. Quintessence Publishing, Germany. ISBN 1850971773
Kwon SR, Kurti SR, Oyoyo U, Li Y (2015a) Effect of various tooth whitening modalities on microhardness, surface roughness and surface morphology of the enamel. Odontology 103:274–279
Kwon SR, Meharry M, Oyoyo U, Li Y (2015b) Efficacy of do-it-yourself whitening as compared to conventional tooth whitening modalities; an in vitro study. Oper Dent 40:E21–E27

Kwon SR, Cortez E, Wang M, Jagwani M, Oyoyo U, Li Y (2020) Systematic review of in vitro studies evaluating tooth bleaching efficacy. Am J Dent 33:17–24
Latimer JS (1868) Notes from the discussion of the society of dental surgeons in the city of New York. Dent Cosmos 10:257–258
Leonard RH Jr (2003) Long-term treatment results with night guard vital bleaching. Compend Contin Educ Dent 24:364–374
Lussi A, Hellwog E, Zero D, Jaeggi T (2006) Erosive tooth wear: diagnosis, risk factors and prevention. Am J Dent 19:319–325
Lynch E (2004) Ozone: the revolution in dentistry. Quintessence Publishing, Batavia, IL. ISBN 1-85097-088-2
Maghaireh GA, Alzraikat H, Guidoum A (2014) Assessment of the effect of casein phosphopeptide-amorphous calcium phosphate on postoperative sensitivity associated with in-office vital tooth whitening. Oper Dent 39:239–247
Matis BA, Gaiao U, Blackman D, Schultz FA, Eckert GJ (1999) In vivo degradation of bleaching gel used in whitening teeth. J Am Dent Assoc 130:227–235
Miara P (2000) An innovative chairside bleaching protocol for treating stained dentition: initial results. Pract Periodontics Anesthet Dent 12:669–676
Mrazek B (2004) Don't bleach until you see the white of their eyes. Compend Contin Educ Dent 25:472–476
Naidu AS, Bennani V, Brunton JMAP, Brunton P (2020) Over-the-counter tooth whitening agents: a review of literature. Braz Dent J 31:221–235
Natural Teeth Whitening Solutions (n.d.). https://www.drozshow.com/article/natural-teeth-whitening-solutions. Accessed 30 Sept 2022
Navarra CO, Reda B, Diolosà M, Casula I, Di Lenarda R, Breschi L, Cadenaro M (2014) The effects of two 10% carbamide peroxide nightguard bleaching agents, with and without desensitizer, on enamel and sensitivity: an in vitro study. Int J Dent Hyg 12:115–120
Nutting EB, Poe GS (1967) Chemical bleaching of discolored endodontically treated teeth. Dent Clin N Am 11:655–662
Ontiveros JC, Paravina RD (2009) Color change of vital teeth exposed to bleaching performed with and without supplementary light. J Dent 37:840–847
Paravina RD (2008) New shade guide for tooth whitening monitoring: visual assessment. J Prosthet Dent 99:178–184
Paravina RD, Perez MM, Ghinea R (2019) Acceptability and perceptibility thresholds in dentistry: a comprehensive review of clinical and research applications. J Esthet Restor Dent 31:103–112
Pashley DH (1989) Dentin: a dynamic substrate-a review. Scanning Microsc 3:161–174
Pearson HH (1958) Bleaching of the discolored pulpless tooth. J Am Dent Assoc 56:64–68
Pinto MM, de Godoy CH, Bortoletto CC, Olivan SR, Motta LJ, Altavista OM, Lumi K, Sobral AP, Bussadori SK (2014) Tooth whitening with hydrogen peroxide in adolescents: study protocol for a randomized controlled trial. Trials 15:395
Prinz H (1924) Recent improvement in tooth bleaching. Dent Cosmos 66:558–560
Reyto R (1998) Laser tooth whitening. Dent Clin N Am 42:755–762
Ribeiro JS, de Oliveira da Rosa WL, da Silva AF, Piva E, Lund RG (2020) Efficacy of natural, peroxide-free tooth-bleaching agents: a systematic review, meta- analysis, and technological prospecting. Phytother Res 34:1060–1070
Rosenthal P (1911) The combined use of ultra-violet rays and hydrogen dioxide for bleaching teeth. Dent Cosmos 53:246–247
Serraglio CR, Zanella L, Dalla-Vecchia KB, Rodrigues-Junior SA (2016) Efficacy and safety of over-the-counter whitening strips as compared to home-whitening with 10% carbamide peroxide gel-systematic review of RCTs and metanalysis. Clin Oral Investig 20:1–14
Settembrini L, Gultz J, Kaim J, Scherer W (1997) A technique for bleaching nonvital teeth: inside/outside bleaching. J Am Dent Assoc 128:1283–1284
Spasser HF (1961) A simple bleaching technique using sodium perborate. N Y State Dent J 27:332–334
Stellwagen TC (1870) Bleaching teeth Cosmos Dent 12:625–627

Stewart GG (1965) Bleaching discolored pulpless teeth. J Am Dent Assoc 70:325–328
LA Times (1996) Firm Wins FDA OK. https://www.latimes.com/archives/la-xpm-1996-08-22-fi-36519-story.html. Accessed 30 Sept 2022
Wang Y, Gao J, Jiang T, Liang S, Zhou Y, Matis B (2015) Evaluation of the efficacy of potassium nitrate and sodium fluoride as desensitizing agents during tooth bleaching treatment-A systematic review and meta-analysis. J Dent 43:913–923
Westlake A (1895) Bleaching teeth by electricity. Am J Dent Sci 29:101
Woodnut C (1861) Discoloration of dentine. Dent Cosmos 2:662
Zaragoza VMT (1984) Bleaching of vital teeth: Technique. Estomodeo 9:7–30

Tooth Whitening: How Does It Work?

2

So Ran Kwon

Abstract

Tooth discoloration is classified as extrinsic or intrinsic, with extrinsic stains arising from the accumulation of residue on the surface of the tooth and intrinsic discoloration from stains within the enamel or dentin. For both types of stains, tooth whitening with hydrogen peroxide is a common treatment. Hydrogen peroxide likely exerts its effects by interacting with chromophores within the tooth structure, acting via what is known as the "chromophore effect." Despite having the desired cosmetic effect, however, hydrogen peroxide treatment likely also may affect sound tooth tissue; and the unknowns surrounding unwanted side effects remain a concern. Here, the etiology of extrinsic and intrinsic stains is summarized, as is our current understanding of hydrogen peroxide treatment and mechanisms of action. This information might guide further research and development efforts to create new technology for the treatment of tooth discoloration.

2.1 Etiology of Discolorations

The human tooth is composed of three dental hard tissues – enamel, dentin, and the cementum – which are distinct in their mineral composition and function. Of the three tissues, dental enamel is the most mineralized and is the hardest tissue of the body. Enamel is ~96% mineral, 3% water, and 1% organic matter by weight, whereas dentin is 70% mineral, 20% organic matrix, and 10% water by weight (Nanci 2013). Unlike bone tissue, which remodels itself continuously through balanced bone resorption and formation, the dental hard tissue does not turn over.

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Nonetheless, the enamel interface undergoes continuous, dynamic ion exchange with the oral biofilm, with calcium phosphate apatite crystals moving in both directions to maintain proper mineral balance (Peters 2010). Indeed, enamel and dentin form a semipermeable membrane that allows small molecules to pass into the tooth structure. This property largely accounts for tooth discoloration from extrinsic sources. The key properties that cause enamel and dentin to bind to and retain staining molecules, however, are still not well understood.

2.1.1 Extrinsic Stains

Tooth discoloration is broadly classified as extrinsic or intrinsic, depending on the origin of the stain (Watts and Addy 2001). Extrinsic stains arise due to the accumulation of residue on the enamel surface and can be accentuated by pitting or irregularities of the enamel, salivary composition, salivary flow rates, and poor oral hygiene (Hattab et al. 1999). The affinity of material to the tooth surface plays a critical role in the deposition of extrinsic stains (Plotino et al. 2008). Stains might adhere to the tooth via several types of attractive forces including 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 (Nathoo 1997). Extrinsic stains take on a variety of colors, which reflect the nature of the stain.

Brown stain is a thin and bacteria-free pellicle commonly found on the buccal surface of the maxillary molars and on the lingual surface of the mandibular incisors (Leung 1950). It is commonly associated with poor oral hygiene and likely results from the deposition of tannins found in tea, coffee, and other beverages (Hattab et al. 1999). Tobacco stains present as a tenacious dark-brown discoloration primarily on the cervical one-third to one-half of teeth. The severity of discoloration is influenced by characteristics of the tooth surface rather than the amount of tobacco consumed (Manly 1973).

Black stain is a continuous narrow black line along the gingival margin of the enamel and encircles the tooth (Faunce 1983). It is usually associated with a mucinous plaque that is infiltrated with chromogenic bacteria, primarily *Actinomyces* (Slots 1974). The black stain is ferric sulfide and is formed by the reaction between hydrogen sulfide, a metabolic by-product of bacteria, and iron from the saliva and gingival exudate (Reid et al. 1977). It is more common in females and may occur in individuals with excellent oral hygiene (Goldstein and Garber 1995).

Green stains on the labial surface at the gingival third of the maxillary anterior teeth are attributed to the infiltration and growth of fluorescent bacteria and fungi, such as *Penicillium* and *Aspergillus* (Bartels 1939). It is common in children, affecting boys more frequently than girls (Leung 1950).

Orange stain appears as a yellow, orange, or a reddish-orange line in the cervical third of the incisors (Faunce 1983). The stain is associated with chromogenic bacteria, such as *Serratia marcescens* and *Flavobacterium lutescens* (Carranza and Newman 1996).

Metallic stains are common in industrial workers exposed to metal-containing dust or in individuals who have received certain orally administered drugs or locally applied therapeutic agents (Hattab et al. 1999). The metal that combines with the acquired pellicle at the tooth surface varies the stain color: Dust composed of mercury and lead are gray, copper and nickel stains are green to blue-green, and chromic acid fumes produce a deep orange color in the enamel. The use of iodine solution and stannous fluoride produces a brown discoloration, while silver nitrate results in a black discoloration (Hattab et al. 1999). Antiseptic stain has been observed after prolonged use of chlorhexidine mouth rinses and is characterized by a brown, diffuse discoloration of the teeth (Linden et al. 1986). Despite the fact that extrinsic discolorations may vary in color, severity, and location, all stains can be easily removed by dental prophylaxis.

2.1.2 Intrinsic Stains

In contrast to the superficial nature of extrinsic stains, intrinsic discolorations are incorporated during tooth formation or after eruption and are attributable to the presence of stain molecules within the enamel and dentin (Dahl and Pallesen 2003). Preeruptive stains arise due to dental fluorosis, tetracycline staining, hematologic disorders, and inherited developmental defects of enamel or dentin without systemic features (Hattab et al. 1999).

2.1.2.1 Dental Fluorosis

Because it is widely available from multiple sources, dental fluorosis is the most common cause of intrinsic discoloration and manifests as a subsurface hypomineralization of tooth enamel caused by chronic ingestion of fluoride during odontogenesis (Burt 1992). The nature and severity of dental fluorosis depends on the dosage, duration of exposure, stage of ameloblast activity, and susceptibility of the individual (Driscoll et al. 1983). Initially, tooth discoloration may not be evident upon eruption but becomes more evident as the exposed porous surface gradually absorbs chromogenic substances in the oral cavity (Steinberg et al. 1999). Clinically, signs of mild fluorosis range from delicate accentuation of the perikymata pattern to white opaque spots or lines. In severe cases, brown pitting patches or localized loss of external enamel may occur (Hattab et al. 1999).

2.1.2.2 Tetracycline Staining

Tetracycline staining was first reported in the late 1950s after its introduction and widespread use as a broad-spectrum bacteriostatic antibiotic (Shwachman et al. 1958). Tetracycline exposure between the second trimester in utero to approximately 8 years of age can affect the teeth, skeleton, and fingernails (Bevelander 1964). The tetracycline molecule chelates with calcium in hydroxyapatite crystals, predominantly in dentin, forming a tetracycline-calcium orthophosphate complex (Mello 1967). The color of tetracycline-stained teeth becomes more intense upon chronic exposure to sun and artificial light because of the photooxidation of this

complex (McEvoy 1989). The severity of stains depends on the type of tetracycline consumed and the time, duration, and amount of drug intake (Dayan et al. 1983). Proper diagnosis is imperative as tetracycline staining is considered one of the most difficult stains to remove. Diagnosis is established by acquiring patient history and assessing clinical appearance and fluorescence under ultraviolet light (Hattab et al. 1999).

2.1.2.3 Developmental Defects and Others

Developmental defects of enamel or dentin are associated with amelogenesis imperfecta, dentinogenesis imperfecta, and enamel hypoplasia. Discolorations due to developmental defects often become worse over time as the rough surfaces allow stains to accumulate more easily. Numerous other factors can also adversely affect the ameloblast and cause enamel hypoplasia, including nutritional deficiencies, viral exanthematous diseases, trauma to developing teeth, birth trauma, metabolic diseases, hemolytic diseases in newborns, local infection, ingestion of chemicals, and other genetic factors (Hattab et al. 1999).

Intrinsic stains can also be acquired after eruption resulting in local discoloration. The severity of the discoloration varies depending on the cause and may appear mild yellow-orange to very dark brown or black. Dental caries is a major cause of local discoloration and often starts as an opaque, white halo, ultimately developing into an unsightly brown or black area due to the reaction of bacterial by-products with decalcified dentin (Eriksen and Nordbo 1978). Restorative materials that leak around the margins may allow debris or chemicals to enter, resulting in discoloration of the underlying dentin (Steinberg et al. 1999). Amalgam pigmentation is very common and can result in greenish-black pigmentation caused by the products of tin oxidation (Goldstein and Garber 1995). Endodontic materials and sealers also have various staining potentials that over time cause intrinsic discoloration of a tooth with a filled root canal (van der Burgt and Plasschaert 1985).

The success of tooth whitening depends upon proper diagnosis of the initial cause of discoloration. Although stains are categorized as extrinsic or intrinsic, in most cases the etiology is multifactorial. Further, extrinsic stains often become internalized over time as the enamel and dentin are permeable to organic and inorganic substances. Therefore, careful examination and history taking are required to properly determine all components that contributed to the discoloration.

2.2 Mechanism of Peroxide Action

The importance of appearance in our society has increased the demand for instant tooth whitening, resulting in a prolific and diverse array of products and techniques. To keep pace with this trend, dental professionals have invested a great amount of effort to elucidate the mechanisms through which peroxides promote tooth whitening. The “chromophore theory” is based on the interaction of hydrogen peroxide with organic chromophores within the tooth structure and has traditionally been accepted as the mechanism by which peroxide exerts its whitening effects. Organic

chromophores have electron-rich areas, and when reactive oxygen species such as hydrogen peroxide encounter stain molecules, they convert the chromophore chains into simpler structures or alter their optical properties and diminish the appearance of the stain (Albers 1991). Although the chromophore theory is widely adopted, it is not fully understood, and many fundamental questions remain: How do organic chromophores diffuse into the tooth? How do they interact with tooth structure? Where do they accumulate? What is the composition and fate of the breakdown products of any oxidation process? These questions merit further investigation.

To facilitate understanding of tooth whitening, the process can be evaluated in three distinct phases: (1) the movement of the whitening agent applied from the outer surface into the enamel and dentin, (2) the interaction of stain molecules with hydrogen peroxide upon its penetration into the tooth structure, and (3) the micromorphological changes induced by peroxide-based materials on tooth surface and structure that may lead to optical changes. The combined dynamics of diffusion, interaction, and micromorphological changes is illustrated in Fig. 2.1. The outcome of these three phases yields the final color change of the tooth after whitening. Ideally, whitening agents will maximize lightening while minimizing concurrent damage to the tooth structure (Kwon and Wertz 2016). Investigating the effects of peroxide during each phase will increase our understanding of the whitening process and optimize whitening approaches.

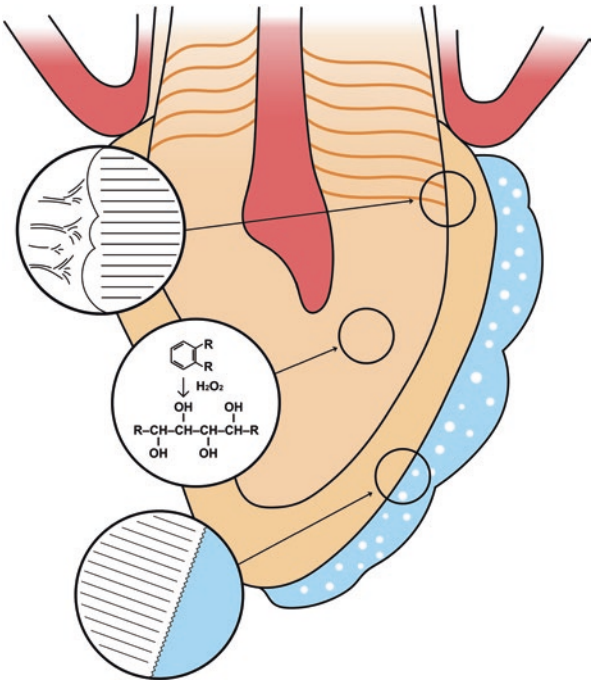

Fig. 2.1 The mechanism of tooth whitening through the dynamics of diffusion, interaction, and micromorphological surface changes. Upper insert: The whitening material applied on the outer tooth surface penetrates into the enamel and diffuses into the terminal branches of dentinal tubules at the cementoenamel junction. Middle insert: Hydrogen peroxide interacts with stain molecules/chromogens and oxidizes them into more simple molecules. Lower insert: potential micromorphological surface changes that can alter light absorption and reflection

2.2.1 Phase 1: Diffusion

Extrinsic stains that are limited to the external surface of the tooth can be readily removed with toothbrushing or dental prophylaxis. However, once the stain becomes internalized within the enamel and dentin, hydrogen peroxide must penetrate these layers in order to interact with organic chromophores. Although peroxide-based tooth whitening was introduced in the 1800s, the quantification of hydrogen peroxide penetration into the pulp cavity was not quantified until 1987 by Bowles and Ugwuneri (Bowles and Ugwuneri 1987). This in vitro study used Leucocrystal violet and horseradish peroxidase to spectrophotometrically measure hydrogen peroxide at submicrogram levels and is a well-established, accurate, selective, and sensitive analytical method that is still used today (Mottola et al. 1970).

Studies evaluating the diffusion phase found that peroxide penetration was enhanced by the following: higher hydrogen peroxide concentrations (Bowles and Ugwuneri 1987; Gökay et al. 2004; Hanks et al. 1993; Palo et al. 2010); prolonged application (Hanks et al. 1993; Kwon et al. 2012b; Rotstein et al. 1991); increased temperature (Bowles and Ugwuneri 1987; Rotstein et al. 1991); the large size of dentinal tubules in young teeth (Camps et al. 2007); variations in tooth structure due to location, acid etching, or restorations (Benetti et al. 2004; Camargo et al. 2007; Camps et al. 2010; Palo et al. 2012; Patri et al. 2013); and light activation (Camargo et al. 2009). Penetration was also improved by specific formulations and delivery systems (Bharti and Wadhwani 2013; Cooper et al. 1992; Gökay et al. 2005; Park et al. 2016; Pignoly et al. 2012; Thitinanthapan et al. 1999). The results of all reviewed studies are in accordance with Fick's second law of diffusion, which states that the diffusion of a molecule is proportional to the surface area, diffusion coefficient, and concentration and that it is inversely proportional to the diffusion distance (Brotherton Boron 1994).

Additionally, studies were performed to determine the path of diffusion into the tooth by whitening agents. Since peroxide-based materials are water soluble, it was speculated that the diffusion of these molecules was similar to the flow of fluids that occur in the enamel interprismatic spaces and dentinal tubules (Ake-Linden 1968; Kwon et al. 2012a; Pashley 1996). In a study utilizing confocal laser scanning microscopy, the diffusion pathway of hydrogen peroxide was correlated to rhodamine B. This demonstrated diffusion of the dye into interprismatic spaces and accumulation along the dentin-enamel junction, followed by uptake into the terminal branch of the dentinal tubules where it could directly access the predentin and pulp cavity (Kwon et al. 2012a). However, this is not simply passive diffusion of these molecules but requires a concentration gradient that is determined by the chemical affinity for each dental tissue (Ubaldini et al. 2013). Thus, as chemical composition can affect the outcome of treatment, it is important to identify the optimal whitening concentration and application times so that concurrent tooth structure damage may be minimized without compromising whitening efficacy.

2.2.2 Phase 2: Interaction

Although a wide variety of whitening products are available, most contain hydrogen peroxide as the active agent (Dahl and Pallesen 2003). Hydrogen peroxide may be applied directly or produced in a chemical reaction from sodium perborate or carbamide peroxide (Budavari et al. 1989). Hydrogen peroxide (H_2O_2) is slightly more viscous than water with a molar mass of 34.0147 g/mol and acts as a strong oxidizing agent (Hess 1995). The rate of decomposition and the type of active oxygen formed depend on the temperature and concentration of peroxide, as well as the pH and presence of cocatalysts and metallic reaction partners (Goldstein and Garber 1995).

Homolytic cleavage, the splitting of shared, bonding electrons resulting in an unshared electron

$$\mathrm{HOOH} \rightarrow \mathrm{H}\cdot + \cdot\mathrm{OOH} \text{ or } \mathrm{HO}\cdot + \cdot\mathrm{OH}$$

This type of cleavage is favored by light and heat and forms free radicals.

Heterolytic cleavage, which is a deprotonation reaction leaving an electron pair

$$\mathrm{HOOH} \rightarrow \mathrm{H}^{+} + \cdot\mathrm{OOH}^{-}$$

This deprotonation occurs at increased pH and generates perhydroxyl anions (Feinman et al. 1991).

A third pathway is derived by a *combination of homolytic and heterolytic cleavage* and generates active oxygen that is both an anion and a free radical:

$$\mathrm{HOO}\cdot + \mathrm{OH}^{-} \rightarrow \mathrm{O}\cdot{}^{-}{}_{2} + \mathrm{H_2O}\,(\text{basic condition}) \text{ and}$$
$$\mathrm{HOO}\cdot \rightarrow \mathrm{O}\cdot{}^{-}{}_{2} + \mathrm{H}^{-}\,(\text{acidic condition})$$

Active oxygen is attracted to electron-rich areas of stain molecules and cleaves double bond to reduce color or remove the compound (Albers 1991).

Despite the well-known chemistry of hydrogen peroxide and its application to establish the chromophore theory, many issues remain unsolved. Studies using Fourier-transform infrared (FTIR) and Raman spectroscopies failed to detect chromophores or their breakdown products in the enamel and are inconsistent with the chromophore theory (Darchuk et al. 2008; Eimar et al. 2012; Fattibene et al. 2005). Thus, continued investigation is required to fully understand the mechanisms of hydrogen peroxide in eliminating stains.

Ideally, as hydrogen peroxide moves from the external tooth surface into the enamel and dentin, its oxidizing action should be limited to organic chromophores until it reaches a certain saturation point or whitening threshold. Oxidizing action beyond the whitening threshold – characterized by the depletion of chromophores – has been cautioned against as it might compromise tooth structure. Indeed, review of the literature suggests hydrogen peroxide has significant interactions with the organic and inorganic components of enamel and dentin well before the saturation point. This may account for alterations in the physical properties of the tooth substrate after the whitening treatment (Attin et al. 2005).

Extensive studies using ion-selective electrode probes, FT-Raman spectroscopy, and a combination of scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometer and microcomputerized tomography suggest that hydrogen peroxide interacts with the tooth structure and changes the chemical composition of enamel and dentin (Kwon and Wertz 2016). While evidence exists that peroxide-based materials do not irreversibly influence the chemistry of enamel and dentin beyond clinical relevance (Arcari et al. 2005; Cavalli et al. 2011; Goo et al. 2004; Lee et al. 2006; Mc Cracken and Haywood 1996; Rodrigues et al. 2007), several studies have demonstrated significant changes in the calcium/phosphate ratio, indicative of alterations in the inorganic components of hydroxyapatite (Al-Saleni et al. 2007; Berger et al. 2010; Bizhang et al. 2006; de Freitas et al. 2004; Efeoglu et al. 2005; Efeoglu et al. 2007; Rotstein et al. 1996; Rotstein et al. 1992). Microcomputerized tomography studies of enamel treated with 10% or 35% carbamide peroxide demonstrated a demineralization depth of 50 μm and 250 μm, respectively (Efeoglu et al. 2005; Efeoglu et al. 2007). Furthermore, infrared spectroscopic analysis showed changes in the enamel that was both concentration and time dependent.

It is worth noting that changes in the organic component of enamel and dentin are likely due to the oxidizing ability of hydrogen peroxide, while changes in the mineral component are mainly attributed to its acidity (Jiang et al. 2007). Several studies provide evidence supporting that the organic matrix of enamel and dentin is oxidized by hydrogen peroxide. X-ray diffraction analysis of hydroxyapatite suggests hydrogen peroxide influences the organic tissue, and nuclear magnetic resonance-based measurements indicate proline and alanine may be more susceptible to an attack by the hydroxyl radical (Kawamoto and Tsujimoto 2004; Sato et al. 2013; Toledano et al. 2011). Other studies assessing morphological changes in the enamel and dentin used atomic force microscopy (AFM) and FTIR to show the tooth enamel matrix protein or organic matrix of dentin had partially lysed, causing these effects (Abouassi et al. 2011; Chng et al. 2005; Hegedüs et al. 1999; Mahringer et al. 2009; Sato et al. 2013; Ubaldini et al. 2013). Moreover, other studies have implicated that proteolysis by dentin metalloproteinases and cathepsin B might also compromise the organic component of dentin (Sato et al. 2013; Toledano et al. 2011).

Collectively, these studies demonstrate that hydrogen peroxide indeed interacts with all components of dentin and enamel. Thus, it may not only target chromophore stains but also whiten by modifying the organic substances within the tooth. Future studies must identify the clinical significance of interactions between hydrogen peroxide and each tooth layer.

2.2.3 Phase 3: Surface Change and Color

The anticipated final outcome of tooth whitening is to increase color lightness and reduce chroma in the yellow-blue and red-green spectrum based on the CIE Lab system (Commission Internationale de l'Eclairage 1995). The separate contributions of enamel and dentin on tooth color have been evaluated, with some studies

placing more emphasis on the role of dentin (Kwon et al. 2013; Wiegand et al. 2005). Nevertheless, enamel characteristics also play a key role in the optical properties of the tooth. Enamel contributes to the overall tooth color by decreasing the translucency of the tooth, masking of the color of the underlying dentin (Kawamoto and Tsujimoto 2004; Ma et al. 2009; Ma et al. 2011). Changes in the enamel have been attributed to micromorphological alterations through deproteinization, demineralization, and oxidation of the most superficial enamel layer (Eimar et al. 2011; Ma et al. 2009; Ma et al. 2011). This changes the density of enamel making the distribution of enamel crystals less compact and potentially increasing its refractive index (Li et al. 2010; Ma et al. 2011).

Determining how subtle enamel surface changes affect tooth has been an area of interest. Studies have found that rough surfaces create a more diffuse reflection, turning the object brighter, whereas a smooth surface leads to more specular reflection. Additionally, an increase in backscattering of short wavelengths, reflected as bluish-white, plays a considerable role in the light-scattering of teeth (Joiner 2004). This is most easily demonstrated by the whitish color change in early caries lesions due to the increased opacity of the tooth enamel (Ma et al. 2009; Ma et al. 2011; Vieira et al. 2008). Further, some studies suggest tooth color change that is associated with tooth whitening is mainly due to mineral loss rather than the breakdown of chromophores (Jiang et al. 2007; Kwon et al. 2002; Lee et al. 2006; Mc Cracken and Haywood 1996). The subsequent uptake of minerals after tooth whitening and the reversal of the treatment substantially support this suggestion (Li et al. 2010).

Because of the impact of surface changes on the appearance of tooth color, changes in surface topography have been extensively investigated. SEM and AFM studies showed increased roughness and surface irregularities upon whitening treatment (Ben-Amar et al. 1995; Bitter and Sanders 1993; Hosoya et al. 2003; McGuckin et al. 1992; de Freitas et al. 2020; Pinto et al. 2004; Shannon et al. 1993; Yeh et al. 2005; Zalkind et al. 1996). Notably, most of these changes have not been seen in studies where a remineralizing agent or saliva was used as a storage medium (Duschner et al. 2006; Haywood et al. 1991; Joiner et al. 2004; Scherer et al. 1991; Turkun et al. 2002; White et al. 2003). Thus, continued investigation into the effects of whitening treatments on surface changes and tooth color is necessary in order to prescribe treatments that will have long-lasting effects with minimal changes to the overall structure of the tooth.

This up-to-date review of the literature illustrates that tooth whitening occurs in three distinct phases, challenging the validity of the widely accepted "chromophore effect" as the dominant mechanism of hydrogen peroxide. As such, this theory must be modified to reflect the true complexity of the mechanisms that drive whitening. Indeed, stains are not determined by the properties of the organic staining molecules alone but are also affected by micromorphological alterations on the tooth surface and within the tooth structure; thus, whitening likely affects intact enamel and dentin microstructures, an under-recognized concern (Kwon and Wertz 2016). In future studies, an appreciation of the complexity of the tooth whitening process will spearhead innovation toward materials and techniques that meet the ever-growing interest in safely obtaining a brighter smile.

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References

Abouassi T, Wolkewitz M, Hahn P (2011) Effect of carbamide peroxide and hydrogen peroxide on enamel enamel surface: an in vitro study. Clin Oral Investig 15:673–680

Ake-Linden L (1968) Microscopic observations of fluid flow through enamel in vitro. Department of Oral Histopathology, Karolinska Institute, School of Dentistry, Stockholm, Sweden Report Nr Op.R(4)

Albers H (1991) Lightening natural teeth ADEPT Report 2:1–24

Al-Saleni SK, Wood DJ, Hatton PV (2007) The effect of 24h non-stop hydrogen peroxide concentration on bovine enamel and dentin mineral content and microhardness. J Dent 35:845–850

Arcari GM, Baratieri LN, Maia HP, De Freitas SF (2005) Influence of the duration of treatment using a 10% carbamide peroxide bleaching gel on dentin surface microhardness: an in situ study. Quintessence Int 36:15–24

Attin T, Vollmer D, Wiegand A, Attin R, Betke H (2005) Subsurface microhardness of enamel and dentin after different external bleaching procedures. Am J Dent 18:8–12

Bartels HA (1939) A note on chromogenic microorganism from an organic colored deposit of the teeth. Int J Orthod 25:795

Ben-Amar A, Liberman R, Gorfil C, Bernstein Y (1995) Effect of mouthguard bleaching on enamel surface. Am J Dent 8:29–32

Benetti AR, Valera MC, Mancini MN, Miranda CB, Balducci I (2004) In vitro penetration of bleaching agents into the pulp chamber. Int Endod J 37:120–124

Berger SB, Cavalli V, Martin AA, Soares LE, Arruda MA, Brancalion ML, Giannini M (2010) Effects of combined use of light irradiation and 35% hydrogen peroxide for dental bleaching on human enamel mineral content. Photomed Laser Surg 28:533–538

Bevelander G (1964) The effect of tetracycline on mineralization and growth. Adv Oral Biol 1:205–223

Bharti R, Wadhwani K (2013) Spectrophotometric evaluation of peroxide penetration into the pulp chamber from whitening strips and gel: an in vitro study. J Conserv Dent 16:131–134

Bitter NC, Sanders JL (1993) The effect of four bleaching agents on the enamel surface: a scanning electron microscopic study. Quintessence Int 24:817–824

Bizhang M, Seemann R, Duve G, Römhild G, Altenburger JM, Jahn KR, Zimmer S (2006) Demineralization effects of 2 bleaching procedures on enamel surfaces with and without post-treatment fluoride application. Oper Dent 31:705–709

Bowles WH, Ugwuneri Z (1987) Pulp chamber penetration by hydrogen peroxide following vital bleaching procedures. J Endod 13:375–377

Brotherton Boron BJ (1994) Inorganic chemistry encyclopedia of inorganic chemistry. John Wiley & Sons, Bruce King

Budavari S, O'Neill MJ, Smith A, Heckelman PE (1989) The Merck index. An encyclopedia of chemicals, drugs, and biologicals. Merck and Co., Inc., Rahway, NJ

Burt BA (1992) The changing patterns of systemic fluoride intake. J Dent Res 71:1228–1237

Camargo SE, Valera MC, Camargo CH, Gasparoto Mancini MN, Menezes MM (2007) Penetration of 38% hydrogen peroxide into the pulp chamber in bovine and human teeth submitted to office bleach technique. J Endod 33:1074–1077

Camargo SE, Cardoso PE, Valera MC, de Araújo MA, Kojima AN (2009) Penetration of 35% hydrogen peroxide into the pulp chamber in bovine teeth after LED or Nd:YAG laser activation. Eur J Esthet Dent 4:82–88

Camps J, de Franceschi H, Idir F, Roland C, About I (2007) Time-course diffusion of hydrogen peroxide through human dentin: clinical significance for young tooth internal bleaching. J Endod 33:455–459

Camps J, Pommel L, Aubut V, About I (2010) Influence of acid etching on hydrogen peroxide diffusion through human dentin. Am J Dent 23:168–170
Carranza FA, Newman MG (1996) Clinical periodontology, 8th edn. WB Saunders, Philadelphia, PA
Cavalli V, Rodrigues LK, Paes-Leme AF, Soares LE, Martin AA, Berger SB, Giannini M (2011) Effects of the addition of fluoride and calcium to low-concentrated carbamide peroxide agents on the enamel surface and subsurface. Photomed Laser Surg 29:319–325
Chng HK, Ramli HN, Yap AUJ, Lim CT (2005) Effect of hydrogen peroxide on intertubular dentine. J Dent 33:363–369
Commission Internationale de l'Eclairage (1995) Industrial color difference evaluation, CIE Publ.116. Central Bureau of the CIE, Vienna
Cooper JS, Bokmeyer TJ, Bowles WH (1992) Penetration of the pulp chamber by carbamide peroxide bleaching agents. J Endod 18:315–317
Dahl JE, Pallesen U (2003) Tooth bleaching—a critical review of the biological aspects. Crit Rev Oral Biol Med 14:292–304
Darchuk LA, Zaverbna LV, Bebeshko VG, Worobiec A, Stefaniac EA, Van Grieken R (2008) Infrared investigation of hard human teeth tissues exposed to various doses of ionizing radiation from the 1986 Chernobyl accident. Spectros Int J 22:105–111
Dayan D, Heifferman A, Gorski M, Begleiter A (1983) Tooth discoloration-extrinsic and intrinsic factors. Quintessence Int Dent Dig 14:195–199
de Freitas PM, Turssi CP, Hara AT, Serra MC (2004) Monitoring of demineralized dentin microhardness throughout and after bleaching. Am J Dent 17:342–346
de Freitas AC, Espejo LC, Botta SB, de Sa Teixeira F, Luz MA, Garone-Netto N, Matos AB, da Silveira Salvadori MC (2020) AFM analysis of bleaching effects on dental enamel microtopography. Appl Surf Sci 256:2915–2919
Driscoll WS, Horowitz HS, Meyers RJ, Heifetz SB, Kingman A, Zimmerman ER (1983) Prevalence of dental caries and dental fluorosis in areas with optimal and above-optimal water fluoride concentrations. J Am Dent Assoc 107:42–47
Duschner H, Götz H, White DJ, Kozak KM, Zoladz JR (2006) Effects of hydrogen peroxide bleaching strips on tooth surface colour, surface microhardness, surface and subsurface ultrastructure, and microchemical (Raman spectroscopic) composition. J Clin Dent 17:72–78
Efeoglu N, Wood D, Efeoglu C (2005) Microcomputerized tomography evaluation of 10% carbamide peroxide applied to enamel. J Dent 33:561–567
Efeoglu N, Wood DJ, Efeoglu C (2007) Thirty-five percent carbamide peroxide application causes in vitro demineralization of enamel. Dent Mater 23:900–904
Eimar H, Marelli B, Nazhat SN, Nader SA, Amin WA, Torres J, de Albuquerque Jr RF, Tamimi F (2011) The role of enamel crystallography on tooth shade. J Dent 39(Suppl 3):e3–e10
Eimar H, Siciliano R, Abdallah MN, Nader SA, Amin WM, Martinez PP, Celemin A, Cerruti M, Tamimi F (2012) Hydrogen peroxide whitens teeth by oxidizing the organic structure. J Dent 40S:e25–e33
Eriksen HM, Nordbo H (1978) Extrinsic discoloration of teeth. J Clin Periodontol 5:229–236
Fattibene P, Carosi A, De Coste V, Sacchetti A, Nucara A, Postorino P, Dore P (2005) A comparative EPR, infrared and Raman study of natural and deproteinated tooth enamel and dentin. Phys Med Biol 50:1095–1108
Faunce F (1983) Management of discolored teeth. Dent Clin N Am 27:657–670
Feinman RA, Madray G, Yarborough D (1991) Chemical, optical, and physiologic mechanisms of bleaching products: a review. Pract Periodontics Aesthet Dent 3:32–36
Gökay O, Műjdeci A, Algin E (2004) Peroxide penetration into the pulp from whitening strips. J Endod 30:887–889
Gökay O, Müjdeci A, Algin E (2005) In vitro peroxide penetration into the pulp chamber from newer bleaching products. Int Endod J 38:516–520
Goldstein RE, Garber DA (1995) Complete dental bleaching. Quintessence Pub Co., Chicago, IL
Goo DH, Kwon TY, Nam SH, Kim HJ, Kim KH, Kim YJ (2004) The efficiency of 10% carbamide peroxide gel on dental enamel. Dent Mater J 23:522–527

Hanks CT, Fat JC, Wataha JC, Corcoran JF (1993) Cytotoxicity and dentin permeability of carbamide peroxide and hydrogen peroxide vital bleaching materials, in vitro. J Dent Res 72:931–938
Hattab FN, Qudeimat MA, Al-Rimawi HS (1999) Dental discoloration: An overview. J Esthet Dent 11:291–310
Haywood VB, Houck VM, Heymann HO, Crumpler D, Bruggers K (1991) Nightguard vital bleaching: effects of various solutions on enamel surface texture and color. Quintessence Int 22:775–782
Hegedüs C, Bistey T, Flora-Nagy E, Keszthelyi G, Jenei A (1999) An atomic force microscopy study on the effect of bleaching agents on enamel surface. J Dent 27:509–515
Hess WT (1995) Kirk-Othmer encyclopedia of chemical technology, 4th edn. Wiley, New York
Hosoya N, Honda K, Lino F, Arai T (2003) Changes in enamel surface roughness and adhesion of Streptococcus mutans to enamel after vital bleaching. J Dent 31:543–548
Jiang T, Ma X, Wang Y, Zhu Z, Tong H, Hu J (2007) Effects of hydrogen peroxide on human dentin structure. J Dent Res 86:1040–1045
Joiner A (2004) Tooth colour: a review of the literature. J Dent 32:3–12
Joiner A, Thakker G, Cooper Y (2004) Evaluation of a 6% hydrogen peroxide tooth whitening gel on enamel and dentine microhardness in vitro. J Dent 32:27–34
Kawamoto K, Tsujimoto Y (2004) Effects of the hydroxyl radical and hydrogen peroxide on tooth bleaching. J Endod 30:45–50
Kwon SR, Wertz PW (2016) Review on the mechanism of tooth whitening. J Esthet Restor Dent 27:240–257
Kwon YH, Huo MS, Kim KH, Kim SK, Kim YJ (2002) Effects of hydrogen peroxide on the light reflectance and morphology of bovine enamel. J Oral Rehabil 29:473–477
Kwon S, Wertz PW, Li Y, Chan DCN (2012a) Penetration patterns of rhodamine dyes into enamel and dentin: confocal laser microscopy observation. Int J Cosmet Sci 34:97–101
Kwon SR, Li Y, Oyoyo U, Aprecio RM (2012b) Dynamic model of hydrogen peroxide diffusion kinetics into the pulp cavity. J Contemp Dent Pract 13:440–445
Kwon S, Wang J, Oyoyo U, Li Y (2013) Evaluation of bleaching efficacy and erosion potential of four different over-the-counter bleaching products. Am J Dent 26:356–360
Lee KH, Kim HI, Kim KH, Kwon YH (2006) Mineral loss from bovine enamel by a 30% hydrogen peroxide solution. J Oral Rehabil 33:229–233
Leung SW (1950) Naturally occurring stains on the teeth of children. J Am Dent Assoc 41:191–197
Li Q, Xu BT, Li R, Yu H, Wang YN (2010) Quantitative evaluation of colour regression and mineral content change of bleached teeth. J Dent 38:253–260
Linden LA, Bjorkman S, Hattab F (1986) The diffusion in vitro of fluoride and chlorhexidine in the enamel of human deciduous and permanent teeth. Arch Oral Biol 31:33–37
Ma X, Jiang T, Sun L, Wang Z, Zhou Y, Wang Y (2009) Effects of tooth bleaching on the color and translucency properties of enamel. Am J Dent 22:324–328
Ma X, Li R, Sa Y, Liang S, Sun L, Jiang T, Wang Y (2011) Separate contribution of enamel and dentine to overall tooth colour change in tooth bleaching. J Dent 39:739–745
Mahringer C, Fureder M, Kastner M, Ebner A, Hinterdorfer P, Vitkov L, Hannig M, Kienberger F, Schilcher K (2009) Examination of native and carbamide peroxide-bleached human tooth enamel by atomic force microscopy. Ultrastruct Pathol 33:189–196
Manly RS (1973) A structureless recurrent deposit on tooth. J Dent Res 22:479
Mc Cracken MS, Haywood VB (1996) Demineralization effects of 10% carbamide peroxide. J Dent 24:395–398
McEvoy SA (1989) Chemical agents for removing intrinsic stains from vital teeth. I Technique development. Quintessence Int 20:323–328
McGuckin RS, Babin JF, Meyer BJ (1992) Alterations in human enamel surface morphology following vital bleaching. J Prosthet Dent 68:754–760
Mello HS (1967) The mechanism of tetracycline staining in primary and permanent teeth. J Dent Child 34:478–487

Mottola HA, Simpson BE, Gorin G (1970) Absorptiometric determination of hydrogen peroxide in submicrogram amounts with leuco crystal violet and peroxidase as catalyst. Anal Chem 42:410–411

Nanci A (2013) Ten Cate's oral histology. Mosby/Elsevier, St. Louis, MI, pp 192–195

Nathoo SA (1997) The chemistry and mechanisms of extrinsic and intrinsic discoloration. J Am Dent Assoc 128(Suppl):6S–10S

Palo RM, Valera MC, Camargo SE, Camargo CH, Cardoso PE, Mancini MN, Pameijer CH (2010) Peroxide penetration from the pulp chamber to the external root surface after internal bleaching. Am J Dent 23:171–174

Palo RM, Bonetti-Filho I, Valera MC, Camargo CH, Moura-Netto C, Pameijer C (2012) Quantification of peroxide ion passage in dentin, enamel, and cementum after internal bleaching with hydrogen peroxide. Oper Dent 37:660–664

Park S, Kwon SR, Qian F, Wertz PW (2016) Evaluation of various in-office tooth whitening systems on hydrogen peroxide penetration. J dent res 95 spec issue a #0635

Pashley DH (1996) Dynamics of the pulpo-dentin complex. Crit Rev Oral Biol Med 7:104–133

Patri G, Agnihotri RSR, Lakshmi N, Das S (2013) An in vitro spectrophotometric analysis of the penetration of bleaching agent into the pulp chamber of intact and restored teeth. J Clin Diag Res 7:3057–3059

Peters MC (2010) Strategies for noninvasive demineralized tissue repair. Dent Clin N Am 54:507–525

Pignoly C, Camps L, Susini G, About I, Camps J (2012) Influence of in-office whitening gel pH on hydrogen peroxide diffusion through enamel and color changes in bovine teeth. Am J Dent 25:91–96

Pinto CF, Oliveira R, Cavalli V, Giannini M (2004) Peroxide bleaching agent effects on enamel surface microhardness, roughness and morphology. Braz Oral Res 18:306–311

Plotino G, Buono L, Grande NM, Pameijer CH, Somma F (2008) Nonvital tooth bleaching: a review of the literature and clinical procedures. J Endod 34:394–407

Reid JS, Beeley JA, MacDonald DG (1977) Investigations into black extrinsic tooth stain. J Dent Res 56:895–899

Rodrigues JA, Oliveira GP, Amaral CM (2007) Effect of thickener agents on dental enamel microhardness submitted to at-home bleaching. Braz Oral Res 21:170–175

Rotstein I, Torek Y, Lewinstein I (1991) Effect of bleaching time and temperature on the radicular penetration of hydrogen peroxide. Endod Dent Traumatol 7:196–198

Rotstein I, Lehr Z, Gedalia I (1992) Effect of bleaching agents on inorganic components of human dentin and cementum. J Endod 18:290–293

Rotstein I, Dankner CDE, Goldman A, Heling I, Stabholz A, Zalking M (1996) Histochemical analysis of dental hard tissues following bleaching. J Endod 22:23–26

Sato C, Rodrigues FA, Garcia DM, Vidal CMP, Pashley DH, Tjäderhane L, Carrilho MR, Nascimento FD, Tersariol ILS (2013) Tooth bleaching increases dentinal protease activity. J Dent Res 92:187–192

Scherer W, Cooper H, Ziegler B, Vijayaraghavan TV (1991) At-home bleaching system: effects on enamel and cementum. J Esthet Dent 3:54–56

Shannon H, Spencer P, Gross K, Tira D (1993) Characterization of enamel exposed to 10% carbamide peroxide bleaching agents. Quintessence Int 24:39–44

Shwachman H, Fekete E, Kulczycki L, Foley GE (1958–1959) The effect of long-term antibiotic therapy in patients with cystic fibrosis of the pancreas. Antibiot Annu 6:692–699

Slots J (1974) The microflora of black stain on human primary teeth. Scand J Dent Res 82:484–490

Steinberg D, Mor C, Dogan H, Zacks B, Rotstein I (1999) Effect of salivary biofilm on the adherence of oral bacteria to bleached and non-bleached restorative material. Dent Mater 15:14–20

Thitinanthapan W, Satamanont P, Vongsavan N (1999) In vitro penetration of the pulp chamber by three brands of carbamide peroxide. J Esthet Dent 11:259–264

Toledano M, Yamauti M, Osorio E, Osorio R (2011) Bleaching agents increase metalloproteinases-mediated collagen degradation in dentin. J Endod 37:1668–1672

Turkun M, Sevgican F, Pehlivan Y, Aktener BO (2002) Effects of 10% carbamice peroxide on the enamel surface morphology: a scanning electron microscopy study. J Esthet Restor Dent 14:238–244

Ubaldini AL, Baesso ML, Medina Neto A, Sato F, Bento AC, Pascotto RC (2013) Hydrogen peroxide diffusion dynamics in dental tissues. J Dent Res 92:661–665

van der Burgt TP, Plasschaert AJ (1985) Tooth discoloration induced by dental materials. Oral Surg Oral Med Oral Pathol 60:666–669

Vieira GF, Arakaki Y, Caneppele TMF (2008) Spectrophotometric assessment of the effects of 10% carbamide peroxide on enamel translucency. Braz Oral Res 22:90–95

Watts A, Addy M (2001) Tooth discoloration and staining: a review of the literature. Br Dent J 190:309–316

White DJ, Kozak KM, Zoladz JR, Duschner HJ, Götz H (2003) Effects of crest Whitestrips bleaching on surface morphology and fracture susceptibility of teeth in vitro. J Clin Dent 14:82–87

Wiegand A, Vollmer D, Foitzik M, Attin R, Attin T (2005) Efficacy of different whitening modalities on bovine enamel and dentin. Clin Oral Investig 9:91–97

Yeh S-T, Su Y, Lu Y-C, Lee S-Y (2005) Surface changes and acid dissolution of enamel after carbamide peroxide bleach treatment. Oper Dent 30:507–515

Zalkind M, Arwaz JR, Goldman A, Rotstein I (1996) Surface morphology changes in human enamel, dentin and cementum following bleaching, a scanning electron microscopy study. Endod Dent Traumatol 12:82–88

Overall Safety of Peroxides

3

Yiming Li

Abstract

Current tooth whiteners contain peroxides as active ingredients, which release hydrogen peroxide (H_2O_2) in the process of application. The primary source of safety concerns with the peroxide-based tooth whiteners is the capability of H_2O_2 to produce oxidative free radicals or reactive oxygen species (ROS), which have been associated with various pathological consequences including carcinogenesis and degenerative diseases. This chapter will review and discuss the toxicology of H_2O_2, its presence in the human body, and its potential systemic effects, genotoxicity, and carcinogenicity on the basis of evidence available in the literature.

3.1 Background

Safety concerns with peroxide-based tooth whiteners primarily originated from its content of peroxide compounds (Li 1996, 1997, 2011; Li and Greewall 2013). Carbamide peroxide ($CH_6N_2O_3$) and hydrogen peroxide (H_2O_2) are the most commonly used peroxide compounds as the active ingredient in current extracoronal tooth whitening products, while sodium perborate ($NaBO_3$) is primary for intracoronal bleaching procedures (Rotstein and Li 2008). Carbamide peroxide, or urea hydrogen peroxide, is a white crystal or a crystallized powder. Chemically carbamide peroxide is composed of approximately 3.5 parts of H_2O_2 and 6.5 parts of urea; a tooth whitener of 10% carbamide peroxide thus contains approximately 3.5% H_2O_2. Sodium perborate is also a white powder available either as monohydrate, trihydrate, or tetrahydrate. The monohydrate and tetrahydrate forms are

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commonly used for intracoronal bleaching, with H_2O_2 content theoretically around 34% and 22%, respectively. In an aqueous medium, both carbamide peroxide and sodium perborate decompose to release H_2O_2, which, therefore, is the true active ingredient of the peroxide-based tooth whitening products.

3.2 Toxicology of Hydrogen Peroxide

H_2O_2 as a chemical was first identified in 1818, and the well-known Fenton reaction was proposed in 1894. Two enzymes, peroxidase and catalase, found in 1898 and 1901, respectively, were quickly recognized to play important roles in H_2O_2 metabolism in humans. Shortly after the discovery of another important enzyme, superoxide dismutase (SOD), in 1969, research efforts on biological properties of H_2O_2 have significantly increased (Li 1996).

The toxicology of H_2O_2 has been investigated extensively, and there are a number of comprehensive reviews on the topic available in the literature (IARC 1985; ECETOX 1993; Li 1996; SCCP 2005; CEU 2011). A key characteristic of H_2O_2 is its capability of producing reactive oxygen species (ROS), which are known to induce various toxicities, including hydroxyl free radicals that have been implicated in various stages of carcinogenesis (Floyd 1990; Li 1996). Oxidative reactions of ROS with proteins, lipids, and nucleic acids are believed to be involved in a number of potential pathological consequences; the damage by oxidative free radicals may be associated with aging, stroke, and other degenerative diseases (Harman 1981; Floyd et al. 1988; Lutz 1990; Li 1996).

The major mechanism responsible for the observed toxicity of H_2O_2 is believed to be the oxidative reactions and subsequent damage in cells by ROS. In cell culture studies, H_2O_2 is highly cytotoxic at concentrations ranging from 1.7 to 19.7 μg/mL or 0.05 to 0.58 mmol/L (Rubin and Farber 1984; Bates et al. 1985; Ramp et al. 1987; Tse et al. 1991; Woolverton et al. 1993; Hanks et al. 1993; Li 1996, 2003). Hepatocytes were less sensitive to the cytotoxicity of H_2O_2 than fibroblasts and endothelial cells (Sacks et al. 1978; Simon et al. 1981; Rubin and Farber 1984), while human gingival fibroblasts derived from primary cultures and L929 mouse fibroblasts (ATCC CCL 1; Manassas, VA) were found to respond similarly to the cytotoxicity of H_2O_2 (Li 1996).

On the other hand, the human body is equipped with various defensive mechanisms available at cellular and tissue levels to prevent potential damage of H_2O_2 to cells during oxidative reactions and to repair any damages sustained. A number of enzymes, such as catalase, SOD, peroxidase, and selenium-dependent glutathione peroxidase, exist widely in body fluids, tissues, and organs, to effectively metabolize H_2O_2 (Floyd 1990; Li 1996). Simply adding iron chelators and antioxidants or increasing serum concentration in culture media effectively reduces or eliminates the cytotoxicity of H_2O_2 (Sacks et al. 1978; Rubin and Farber 1984). In a cell culture study, 20 mM H_2O_2 was undetectable after 30 min in the culture media alone and after 15 min in the media with bone tissues, indicating decomposition and inactivation of hydrogen peroxide in cell culture systems (Ramp et al. 1987). These enzymes also exist in human saliva; in fact, salivary peroxidase has been suggested to be the

body's most important and effective defense against the potential adverse effects of H_2O_2 (Carlsson 1987). Marshall et al. (2001) found that the human oral cavity, including that of adults, juveniles, infants, and adults with impaired salivary flow, was capable of eliminating 30 mg H_2O_2 in less than 1.5 minutes.

3.3 Peroxides in the Human Body

H_2O_2 was first detected in human respiration in 1880; however, it was not until 1969 when the SOD was discovered. H_2O_2 was recognized as an important by-product in oxygen metabolism of humans (Li 1996, 2011). H_2O_2 is now known as a normal intermediate metabolite in humans. It exists in human serum, and it is present in human breath at levels ranging from 0.34 to 1.0 μg per liter (Sies 1981; Williams et al. 1982). The daily production of H_2O_2 in the human liver is approximately 6.48 grams in a period of 24 h (FDA 1983). An important source of endogenous H_2O_2 is from phagocytic cells, such as neutrophils and macrophages, which play an essential role in defense against various pathological microorganisms.

3.4 Systemic Effects

Systemic effects of H_2O_2 have been investigated for both the acute and chronic exposures. A unique characteristic of H_2O_2 in inducing systemic toxicity is its concentration in addition to the dosage.

The reported acute systemic toxic effects of H_2O_2 in animals vary widely according to the H_2O_2 concentration as well as the application mode. In rats, the intravenous 50% lethal dose (LD_{50}) of H_2O_2 was found to be 21 mg/kg (Spector 1956). Using the up-and-down method, in which the dosing is adjusted up or down according to the outcome (death or survival) of the animal that received the previous dosage, the oral LD_{50} of 4% H_2O_2 solution in male and female rats was estimated at 780 and 600 mg/kg, respectively (Li 1996). The LD_{50} for percutaneous application of H_2O_2 is much higher, which was >7500 mg/kg (FDA 1983). The values of LD_{50} are inversely related to the concentrations of H_2O_2, and they vary markedly between different animal species and strains (IARC 1985; FDA 1983; ECETOX 1993; Li 1996). Tissue responses to topical application of H_2O_2 are also related to the H_2O_2 concentration, but they are usually minimal at low concentrations of ≤3%.

Acute toxicity, including fatalities, has been reported in humans who accidentally ingested large amounts of concentrated H_2O_2 solutions (Spector 1956; Giusti 1973; Giberson et al. 1989; Humberston et al. 1990; Rackoff and Merton 1990; Christensen et al. 1992; Cina et al. 1994; Sherman et al. 1994; Asanza et al. 1995; Ijichi et al. 1997; Rider et al. 2008; Byrne et al. 2014). A retrospective survey of a regional poison control center found that over a 36-month period, 325 cases were caused by H_2O_2 poisoning, which accounted for 0.34% of all the reported causes (Dickson and Caravati 1994); however, the majority of the 325 cases (71%) was pediatric population (age < 18 years), with ingestion of H_2O_2 solution being the most common route of exposure (83% of cases). One major factor associated with

the toxicity of H_2O_2 is its concentration. Ingestion of H_2O_2 solutions of less than 10% usually produces no significant adverse effects, although it may cause mild irritation to mucous membranes that results in spontaneous emesis or mild abdominal bloating (Humberston et al. 1990; Dickson and Caravati 1994). Exposure to H_2O_2 concentrations higher than 10%, however, can result in severe tissue burns and significant systemic toxicity. In addition to the tissue damage caused by oxidative reactions, gas embolism is responsible for various pathological consequences of H_2O_2 ingestion (Rackoff and Merton 1990). Each milliliter of 1% H_2O_2 releases 3.3 mL oxygen; therefore, 10 mL of 30% H_2O_2 can produce 1 L oxygen (Giberson et al. 1989; Humberston et al. 1990). Common symptoms observed in acute toxicity of H_2O_2 include stomach and chest pain, retention of breath, foaming at the mouth, loss of consciousness, motor and sensory disorders, fever, gastric hemorrhage, and liver damage. Although rare, death can occur.

Several animal studies have been conducted on acute systemic toxicity of tooth whiteners containing carbamide peroxide. Oral gavage of 5 g/kg tooth whiteners containing 10% and 22% carbamide peroxide produced no evidence of acute systemic toxicity in rats (Cherry et al. 1993; Adam-Rodwell et al. 1994). One study reported unusually low LD_{50} (87.18 to 143.83 mg/kg) of two products containing 10% carbamide peroxide in female Swiss mice (Woolverton et al. 1993). The reasons for the low LD_{50} values are unclear but may be attributed to differences in animal species, materials, and method. Using the up-and-down method, the LD_{50} of a tooth whitening gel with 10% carbamide peroxide was estimated at 23.02 g/kg in female rats (Li et al. 1996).

Chronic systemic toxicity of H_2O_2 has been investigated using animal models. No visible abnormalities were detected in mice drinking 0.15% H_2O_2 (about 150 mg/kg/day) ad libitum for 35 weeks, and their growth was also normal (FDA 1983). Necropsy results, however, showed changes in the liver, kidney, stomach, and small intestine. Solutions of >1% H_2O_2 (>1 g/kg/day) caused pronounced weight loss and death of mice within 2 weeks. A rat study by Ito et al. (1976) found that, when administered by an oral gastric catheter 6 days weekly for 90 days, the dose of 506 mg/kg suppressed body weight gain, decreased food consumption, and caused changes in hematology, blood chemistry, and organ weights. The principal tissue affected was gastric mucosa, and the effects were local. The no-observed-effect level (NOEL) of H_2O_2 was 56.2 mg/kg/day. Another rat study found that the NOEL of H_2O_2 was 30 mg/kg/day when animals were treated by oral gastric catheter daily for 100 days (Kawasaki et al. 1969). The same study showed no adverse effects in rats receiving the diet containing 6 mg H_2O_2 in 20 g of food.

3.5 Genotoxicity

The genotoxic potential of H_2O_2 has been investigated extensively using microbes, plants, insects, cultured mammalian cells, and animals (IARC 1985; ECETOX 1993; Li 1996; SCCP 2005). In a number of bacterial systems, H_2O_2 induced point mutations or single-strand breaks in DNA. Positive mutagenicity of H_2O_2 has also

been detected in some newer tester strains of the Ames *Salmonella* mutagenicity test; however, effects are eliminated when tested with S9 activation. S9 is a rat liver microsomal preparation that contains various enzymes. It has been found to increase the sensitivity and overall performance of the Ames *Salmonella* mutagenicity test, and therefore, experiments both with and without S9 are required for the Ames *Salmonella* mutagenicity test (Maron and Ames 1983). The results obtained from mammalian cells are similar to those from the Ames *Salmonella* mutagenicity test; i.e., the genotoxic effects of H_2O_2 are detected only in test systems without S9 activation. The effect of S9 on H_2O_2-induced DNA or chromosomal changes in mammalian cells in vitro is believed to originate from the H_2O_2-degrading enzymes in the S9, which is the same as that observed in the Ames *Salmonella* mutagenicity test.

The genotoxicity of H_2O_2 has also been examined using in vivo systems, and results indicate that H_2O_2 is not genotoxic in various animal models (IARC 1985; ECETOX 1993; Li 1996; SCCP 2005). The overall data available so far show that H_2O_2 is genotoxic only in in vitro systems without enzymatic activation. When enzymatic activation is incorporated in in vitro systems or when tested in animals, H_2O_2 is non-genotoxic.

3.6 Carcinogenicity

The carcinogenicity of H_2O_2 was the subject of a number of critical reviews (IARC 1985; ECETOX 1993; Li 1996, 1998, 2000, 2011). Several investigators found no evidence of carcinogenicity of H_2O_2 or carbamide peroxide. Repeated subcutaneous injections of 0.5% H_2O_2 for up to 332 days did not induce tumors in a mouse study (Nakahara and Fukuoka 1959). Another 56-week study showed that 5% carbamide peroxide and 3% H_2O_2 were inactive as tumor promoters (Bock et al. 1975). Klein-Szanto and Slaga in 1982 reported that twice-weekly application of 15% and 30% H_2O_2 on mouse dorsal skin for 50 weeks did not induce any squamous cell carcinomas, and they thus concluded that H_2O_2 at 15% and 30% was not a complete carcinogen. The same study also found that at 15% and 30% concentrations, H_2O_2 was not a tumor initiator but exhibited extremely weak tumor-promoting activity after 25 weeks of twice-weekly application following previous application of the carcinogen DMBA as the initiator. At concentrations <15%, H_2O_2 did not cause tumor promotion. In contrast, Nagata et al. (1973) reported that a single subcutaneous injection of 0.6% H_2O_2 was not carcinogenic, and in fact, repeated applications of 0.6% H_2O_2 on mouse skin significantly inhibited tumor development induced by the potent carcinogen benzo(α)pyrene.

The studies that reported carcinogenicity of H_2O_2 and subsequently generated safety concerns about the use of H_2O_2 or peroxide-containing tooth whiteners were conducted by Ito's group (1981; 1982; 1984) and Weitzman et al. (1986). In the 1981 study by Ito and coworkers, male and female C57Bl/6 J mice received 0.1% or 0.4% H_2O_2 in drinking water for up to 100 weeks, with distilled water as the negative control. An increased incidence of duodenal carcinoma was observed in females

only in the 0.4% H_2O_2 group (4 of 50 mice), and 1 carcinoma was observed in 1 male mouse in each of the 0.1% and 0.4% groups. However, results showed no dose-related incidence of duodenal adenomas. Using standard methods for data analysis in which sexes are analyzed separately, no significant increase in carcinoma incidence was noted in males or females. Statistical significance was achieved only when the data from males and females were combined.

In the second study by Ito's group (1982), three strains of mice, including the C57Bl/6 N strain that was used in the initial study, received 0.1% or 0.4% H_2O_2 solution in drinking water for up to 740 days. Duodenal cancer (pathologically not defined as benign, malignant, carcinoma, or adenoma) was observed only in C57Bl/6 J mice between 420 and 740 days, with an incidence of 1% and 5% for the 0.1% and 0.4% H_2O_2 groups, respectively. However, temporary cessation of H_2O_2 and replacement with distilled water for 10, 20, or 30 days decreased the incidence of lesions in both the stomach and duodenum.

The third study by Ito's group (1984) investigated four strains of mice that received 0.4% H_2O_2 solution in drinking water for 7 months (C57Bl/6 N mice) and 6 months (other three strains). The incidence of duodenal lesions was highly strain-dependent and inversely related to duodenal, liver, and blood catalase activity. C57Bl/6 N mice had low catalase activity, and the number of tumors was 41 times that observed in mice with high catalase activity and about 10 times higher than that for the strain with normal catalase activity. Of particular interest is the observation that another strain of catalase-deficient mice had a lower duodenal tumor incidence, both in total number of tumors and number of tumors per mouse, than that of the C57Bl/6 N mice.

Because of the potential significance of the results reported by Ito's team, these studies were reviewed and carefully evaluated for study design, experimental conduct, and data presentation (FDA 1983; IARC 1985; FDA 1988; ECETOX 1993). Major limitations of the research include unverified H_2O_2 concentration and stability in drinking water, inadequate control and documentation of tumor pathology, and lack of information on food consumption and survival. In addition, these studies did not measure individual animal water intake, which is relevant because reduced water intake may contribute to the development of lesions. When water consumption is decreased, the texture of the stomach contents changes, which may increase the likelihood of tissue injury when coarse materials transverse the duodenum, resulting in an increased rate of cell proliferation or regenerative hyperplasia (Bertram 1991). From a 14-day study in C57Bl/6 N mice, water consumption was found to decrease with increasing H_2O_2 content (Weiner et al. 2000). Therefore, in the same strain of mice, it is appropriate to assume that the decrease in water intake also occurred during H_2O_2 exposure in Ito's studies. As a consequence, gastrointestinal irritation occurred. As observed in Ito studies, changes to the epithelia were primarily localized to the duodenum, indicating that the lesions are not chemically induced but indicative of mechanical irritation. On the other hand, as demonstrated by Ito and coworkers, the C57Bl/6 N mouse strain used in their studies has a low level of duodenal catalase activity and a high spontaneous incidence of premalignant duodenal lesions. The difference in catalase activity among animal strains

likely is one of the reasons that other studies, including one (Ishikawa and Takayama 1984) that used a similar experimental design to the study of Ito's group, have not found carcinogenicity of H_2O_2. As such, after evaluating the Ito studies, the Cancer Assessment Committee (CAC) of the US Food and Drug Administration (FDA) concluded that Ito's studies did not provide sufficient evidence that H_2O_2 was a duodenal carcinogen.

The study by Weitzman et al. (1986) examined the effects of topical application of H_2O_2 on the cheek porch mucosa of male Syrian golden hamsters. Animals were treated twice weekly with DMBA, a carcinogen, in combination with 3% or 30% H_2O_2 for 19 or 22 weeks. Groups receiving DMBA or 30% H_2O_2 alone were also included. Results showed that 30% H_2O_2 alone did not induce any tumors at either of the two time periods. At 19 weeks, no tumors were observed in animals receiving the DMBA and 3% H_2O_2, and 30% H_2O_2 had no tumor-enhancing effect. After 22 weeks, there was no tumor-enhancing effect with 3% H_2O_2. The incidence of carcinomas was higher in animals receiving a combination of 30% H_2O_2 and DMBA (five of five animals) compared to those treated with DMBA alone (three of seven animals), but the significance level was marginal ($p = 0.054$). The significance of the observed increase in incidence of carcinoma associated with 30% H_2O_2 at 22 weeks has been questioned because of the small number of animals used and the marginal statistical significance observed (Li 1996; Marshall et al. 1996). It is also difficult to explain the marked differences in results between the two time periods, an interval of only 3 weeks. In addition, repetitive treatment with H_2O_2 solutions greater than 15% was considered too irritating to tissues to enable detection of tumor-promoting activity, because cells would not survive the toxic effects of high concentrations of H_2O_2 (Klein-Szanto and Slaga 1982). Marshall et al. (1996), using the similar experiment design to the Weitzman study, found that H_2O_2 up to 3% was not carcinogenic or cocarcinogenic. The studies by Weitzman et al. (1986) and Marshall et al. (1996) are particularly significant in that they do not demonstrate a synergistic effect between H_2O_2 and the polycyclic aromatic hydrocarbon DMBA during coadministration. Tumor promotion studies (Bock et al. 1975; Klein-Szanto and Slaga 1982) provide additional evidence for a lack of interaction between chemical carcinogens and H_2O_2. The study by Marshall et al. (1996) found a reduction in tumor incidence following H_2O_2 administration, and such an effect was observed with 3% H_2O_2 and baking soda in the hamster cheek pouch model.

References

Adam-Rodwell G, Kong BM, Bagley DM, Tonucci D, Christina LM (1994) Safety profile of colgate platinum professional tooth whitening system. Compend Contin Edu Dent 17(Suppl):S622–S626

Asanza G, Menchén PL, Castellote JI, Salcedo M, Jaime B, Senent C, Castellanos D, Cos E (1995) Hydrogen peroxide-induced lesions in the digestive tract. Apropos 4 cases. Rev Esp Enferm Dig 87:465–468

Bates EJ, Johnson CC, Lowther DA (1985) Inhibition of proteoglycan synthesis by hydrogen peroxide in cultured bovine cartilage. Biochem Biophys Acta 838:221–228

Bertram T (1991) Gastrointestinal tract. In: Haschek WM, Rousseaux CG (eds) Handbook of toxicologic pathology. Academic Press, New York, pp 195–237
Bock FG, Myers HK, Fox HW (1975) Cocarcinogenic activity of peroxy compounds. J Natl Cancer Inst 55:1359–1361
Byrne B, Sherwin R, Courage C, Baylor A, Dolcourt B, Brudzewski JR, Mosteller J, Wilson RF (2014) Hyperbaric oxygen therapy for systemic gas embolism after hydrogen peroxide ingestion. J Emerg Med 46:171–175
Carlsson J (1987) Salivary peroxidase: an important part of our defense against oxygen toxicity. J Oral Pathol 16:412–416
Cherry DV, Bowers DE Jr, Thomas L, Redmond AF (1993) Acute toxicological effects of ingested tooth whiteners in female rats. J Dent Res 72:1298–1303
Christensen DW, Faught WE, Black RE, Woodward GA, Timmons OD (1992) Fatal oxygen embolization after hydrogen peroxide ingestion. Crit Care Med 20:543–544
Cina SJ, Downs JC, Conradi SE (1994) Hydrogen peroxide: a source of lethal oxygen embolism. Case report and review of the literature. Am J Forensic Med Pathol 15:44–50
Dickson KF, Caravati EM (1994) Hydrogen peroxide - 325 exposures reported to a regional poison control center. J Toxicol Clin Toxicol 32:705–714
ECETOX (1993) Joint assessment of commodity chemicals no. 22 - hydrogen peroxide. European Center for Toxicology of Chemicals, Brussels
FDA (Food and Drug Administration) (1983) Hydrogen peroxide: proposed affirmation of GRAS status as a direct human food ingredient with specific limitations. Fed Regist 1983(48):52323–53333
FDA (Food and Drug Administration) (1988) Irradiation in the production, processing, and handling of food. USPHS FDA 53 FR 53176
Floyd RA (1990) Role of oxygen free radicals in carcinogenesis and brain ischemia. FASEB 4:2587–2597
Floyd RA, West MS, Eneff KL, Hogsett WE, Tingey DT (1988) Hydroxyl free radical mediated formation of 8-hydroxyguanine in isolated DNA. Arch Biochem Biophys 262:266–272
Giberson TP, Kern JD, Pettigrew DW, Eaves CC, Haynes JF (1989) Near fatal hydrogen peroxide ingestion. Ann Emerg Med 18:778–779
Giusti GV (1973) Fatal poisoning with hydrogen peroxide. Forensic Sci 2:99–100
Hanks CT, Fat JC, Wataha JC, Corcoran JF (1993) Cytotoxicity and dentin permeability of carbamide peroxide and hydrogen peroxide vital bleaching materials, in vitro. J Dent Res 72:931–938
Harman D (1981) The aging process. Proc Natl Acad Sci U S A 78:7124–7132
Humberston CL, Dean BS, Krenzelok EP (1990) Ingestion of 35% hydrogen peroxide. J Toxicol Clin Toxicol 28:95–100
IARC (1985) Hydrogen peroxide. IARC monographs on the evaluation of the carcinogenic risk chemicals to humans Vol. 36, pp. 285–314
Ijichi T, Itoh T, Sakai R, Nakaji K, Miyauchi T, Takahashi R, Kadosaka S, Hirata M, Yoneda S, Kajita Y, Fujita Y (1997) Multiple brain gas embolism after ingestion of concentrated hydrogen peroxide. Neurology 48:277–279
Ishikawa T, Takayama S (1984) Cited in: information bulletin on the survey of chemicals being tested for carcinogenicity. 1984; 11:86
Ito R, Kawamura H, Chang HS, Toda S, Matsuura S, Hidano T, Nakai S, Inayoshi Y, Matsuura M, Akuzawa K (1976) Safety study on hydrogen peroxide: acute and subacute toxicity. J Med Society Toho Japan 23:531–537
Ito A, Watanabe H, Naito M, Naito Y (1981) Induction of duodenal tumors in mice by oral administration of hydrogen peroxide. Gan 72:174–175
Ito A, Naito M, Naito Y, Watanabe H (1982) Induction and characterization of gastro-duodenal lesions in mice given continuous oral administration of hydrogen peroxide. Gan 73:315–322
Ito A, Watanabe H, Naito M, Naito Y, Kawashima K (1984) Correlation between induction of duodenal tumor by hydrogen peroxide and catalase activity in mice. Gan 75:17–21

Kawasaki C, Kondo M, Nagayama T, Takeuchi Y, Nagano H (1969) Effect of hydrogen peroxide on the growth of rats. J Food Hyg Soc Jpn 10:68–72
Klein-Szanto AJP, Slaga TJ (1982) Effects of peroxides on rodent skin: epidermal hyperplasia and tumor promotion. J Invest Dermatol 79:30–34
Li Y (1996) Biological properties of peroxide-containing tooth whiteners. Food Chem Toxicol 34:887–904
Li Y (1997) Toxicological considerations of tooth bleaching using peroxide-containing agents. J Am Dent Assoc 128:31S–36S
Li Y (1998) Tooth bleaching using peroxide-containing agents: current status of safety issues. Compend Contin Educ Dent 19:783–796
Li Y (2000) Peroxide-containing tooth whiteners: an update on safety. Compend Contin Educ Dent 21(Suppl 28):S4–S9
Li Y (2003) The safety of peroxide-containing at-home tooth whiteners. Compend Contin Educ Dent 24:384–389
Li Y (2011) Safety controversies in tooth bleaching. Dent Clin N Am 55:255–263
Li Y, Greewall L (2013) Safety issues of tooth whitening using peroxide-based materials. Br Dent J 215:29–34
Li Y, Noblitt T, Zhang W, Schymik M, Fang S, Kafrawy A, Xu Y, Klaunig JE, Stookey GK (1996) Safety evaluation of opalescence sustained release whitening gel. J Dent Res 75:430
Lutz WK (1990) Endogenous genotoxic agents and processes as a basis of spontaneous carcinogenesis. Mutation Res 238:287–295
Maron DM, Ames BN (1983) Revised methods for the salmonella mutagenicity test. Mutat Res 113:173–215
Marshall MV, Kuhn JO, Torrey CF, Fischman SL, Cancro LP (1996) Hamster cheek pouch bioassay of dentifrices containing hydrogen peroxide and baking soda. J Am Coll Toxicol 15:45–61
Marshall MV, Gragg PP, Packman EW, Wright PB, Cancro LP (2001) Hydrogen peroxide decomposition in the oral cavity. Am J Dent 14:39–45
Nagata C, Tagashira T, Kodama M, Loki Y, Oboshi S (1973) Effect of hydrogen peroxide, Fenton's reagent, and iron ions on the carcinogenicity of 3,4-benzopyrene. Gan 64:277–285
Nakahara W, Fukuoka F (1959) On the mechanism of radiation carcinogenesis. Gan 50:17–21
Rackoff WR, Merton DF (1990) Gas embolism after ingestion of hydrogen peroxide. Pediatrics 85:593–594
Ramp WK, Arnold RR, Russell JE, Yancey JM (1987) Hydrogen peroxide inhibits glucose metabolism and collagen synthesis in bone. J Periodontol 58:340–344
Rider SP, Jackson SB, Rusyniak DE (2008) Cerebral air gas embolism from concentrated hydrogen peroxide ingestion. Clin Toxicol (Phila) 46:815–818
Rotstein I, Li Y (2008) Tooth discoloration and bleaching. In: Ingle JI, Bakland LK, Baumgartner JC (eds) Ingle's endodontics, 6th edn. BC Decker Inc., Hamilton, pp 1383–1399
Rubin R, Farber JL (1984) Mechanisms of the killing of cultured hepatocytes by hydrogen peroxide. Arc Biochem Biophys 228:450–459
Sacks T, Moldow CF, Craddock PR, Bowers TK, Jacob HS (1978) Oxygen radicals mediate endothelial cell damage by complement-stimulated granulocytes, an in vitro model of immune vascular damage. J Clin Invest 61:1161–1167
Scientific Committee on Consumer Products (SCCP) (2005) Opinion on Hydrogen Peroxide in Tooth Whitening Products Adopted by the SCCP during the 3rd plenary meeting of 15 March 2005. http://ec.europa.eu/health/ph_risk/committees/04_sccp/docs/sccp_o_022.pdf, 2005
Sherman SJ, Boyer LV, Sibley WY (1994) Cerabral infarction immediately after ingestion of hydrogen peroxide solution. Stroke 25:1065–1067
Sies H (1981) Measurement of hydrogen peroxide formation in situ. In: Swern D (ed) Methods in enzymology, Vol. 77. Detoxification and drug metabolism: conjugation and related systems. Academic Press, New York, pp 15–20
Simon RH, Scoggins CH, Patterson D (1981) Hydrogen peroxide causes the fatal injury to human fibroblasts exposed to oxygen radicals. J Biol Chem 256:7181–7186

Spector WS (1956) Acute toxicities of solids, liquids and gases to laboratory animals. In: Spector WS (ed) Handbook of toxicology, vol 1. Saunders, Philadelphia, PA, p 160

The Council of The European Union (CEU) (2011) Council directive 2011/84/EU, amending directive 76/768/EEC concerning cosmetic products. Offic J Eur Union:L283/36–L283/38

Tse CS, Lynch E, Blake DR, Williams DM (1991) Is home tooth bleaching gel cytotoxic? J Esthet Dent 3:162–168

Weiner ML, Freeman C, Trochimowicz H, Brock W, De Gerlache J, Malinverno G, Mayr W, Regnier JF (2000) A 13-week drinking water study with 6-week recovery period in catalase-deficient mice with hydrogen peroxide. Food Chem Toxicol 38:607–615

Weitzman SA, Weitberg AB, Stossel T, Schwartz J, Shklar G (1986) Effects of hydrogen peroxide on oral carcinogenesis in hamsters. J Periodontol 57:685–688

Williams MD, Leigh JS Jr, Chance B (1982) Hydrogen peroxide in human breath and its probable role in spontaneous breath luminescence. Ann N Y Acad Sci 386:478–483

Woolverton CJ, Haywood VB, Heymann HO (1993) Toxicity of two carbamide peroxide products used in nightguard vital bleaching. Am J Dent 6:310–314

Complications from the Use of Peroxides

4

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4.1 Introduction

Tooth bleaching is a cosmetic procedure that is widely used owing to its technical simplicity, proven clinical efficacy, and noninvasiveness, as it does not require removal of tooth structure. This procedure is based on the oxidative potential of hydrogen peroxide (H_2O_2), the main active component of bleaching agents used for vital teeth. This molecule can diffuse through the tooth enamel and promote the breakdown of organic pigments present in the dentin. The two bleaching techniques traditionally used under the supervision of a dentist are the at-home and the in-office bleaching techniques. The former is considered the safest for the patient, as gels containing low concentrations of carbamide peroxide (CP) or H_2O_2 are used for tooth bleaching. Although the dentist supervises this technique, the product is applied at home by the patient who completes the treatment using customized acetate trays. This bleaching procedure has raised questions about the risks of systemic toxicity and the indiscriminate and/or inappropriate use of bleaching products by patients, which may increase the risk of adverse effects on oral tissues.

Traditionally, the in-office technique involves the use of H_2O_2-based gels in high concentrations (30–40%). This procedure is performed in the dental office under

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full control of the dentist. However, the use of H_2O_2 in high concentrations results in the diffusion of the molecule to reach toxic levels into the pulp chamber, resulting in important changes in the pulp connective tissue that have been linked to high levels of post-bleaching sensitivity. In addition, extreme caution should be taken to protect oral soft tissues and prevent swallowing of the bleaching material, as contact of this product with oral mucous membrane can cause chemical burns, which may result in severe discomfort for the patient.

Recent studies have attempted to remove bleaching protocols from the empiricism where they have been. In the past many clinicians did not consider the scientific evidence related to the effectiveness of the treatment and the biological safety of tooth bleaching (Esteves et al. 2022a,b; Soutomaior 2019; Cavalli et al. 2019; Duque et al. 2017). These adjustments are necessary, not only because the literature provided by manufacturers of dental bleaching products offers little detailed information about the amount and how the material should be applied, but also because these precautions could lead to the reduction of side effects and increase the biological safety of the procedure.

In clinical practice, tooth sensitivity and gingival tissue irritation are the most frequently reported adverse effects by patients who undergo different bleaching techniques. However, in addition to the adverse effects observed in soft tissues, tooth bleaching is now scientifically proven to cause changes in mineralized tissues and in preexisting restorations, the extent of which depends on the technique used. Thus, in this chapter, we will discuss changes in soft tissue, mineralized tissues, and adhesive restorations caused by the different bleaching techniques currently available, and the clinical aspects related to post-bleaching tooth sensitivity.

4.2 Effect on Oral Soft Tissues

H_2O_2 has been extensively shown in the literature to cause major changes in various cell types (Zhu et al. 2012). Therefore, the contact of the molecule with biological tissues such as gingival tissue, periodontal ligament, and pulp tissue during bleaching is not desirable in terms of preventing significant side effects. As bleaching products with different H_2O_2 concentrations, presentation forms, and application protocols are available for clinical or at-home use, distinct cellular responses are expected according to the therapy used. Thus, the dentist should be aware of the possible adverse effects of each therapy in order to use the best clinical alternative in each specific situation. In this chapter, greater emphasis will be given on the effects of the different bleaching techniques on gingival and periodontal tissues. The effect of these procedures on the pulp tissue is described in detail in Chap. 5.

Direct contact of the bleaching gel with oral soft tissues can cause chemical burn due to the caustic potential of H_2O_2, resulting in the development of gingival ulcers and erosions. H_2O_2 may also cause changes in the periodontal tissue that can lead to gum recession. The magnitude of these effects is proportional to the contact time and concentration of H_2O_2 in the bleaching product (Powell and Bales 1991;

Haywood et al. 1997; da Costa Filho et al. 2002). These negative effects can be prevented in the in-office technique by careful application of a gingival barrier, which effectively prevents the contact of the gingival tissue and periodontal ligament with the whitening gel. For the supervised at-home technique, the fabrication of an adequate tray with clear instructions for use given by the practitioner is indispensable to prevent irritation of oral tissues. However, many over-the-counter (OTC) products are available for use without dentist supervision. Some of them are applied in trays with poor adaptation to the dental arches, which can increase the risk of contact of the bleaching agent with the periodontal tissues, especially in patients with tooth misalignment. In addition, bleaching strips with various H_2O_2 concentrations have gained popularity mainly because they do not require the use of trays. However, these systems result in direct contact of the bleaching strip with the gingival papilla, as they are not customized to fit the individual dental arches of patients. The biological effects of different types of bleaching on soft oral tissues are discussed in the following sections based on scientific evidence available in the current literature.

4.2.1 At-Home Bleaching

The supervised at-home bleaching technique is based on the use of bleaching gels containing 10–22% CP or 4–10% H_2O_2. However, only 10% CP has received the American Dental Association (ADA) seal of approval. Thus, at-home bleaching that involves the use of gels containing 10% CP has been considered the safest treatment modality. In fact, the recent literature has provided reports on the monitoring of esthetic and biological effects up to 17 years posttreatment (Boushell et al. 2012).

CP is a product of the weak link between H_2O_2 and urea, which is easily broken in the presence of water, releasing about 3.3% H_2O_2 in the process (Kwon et al. 2002; Sulieman 2008). Thus, the mechanism of action of home bleaching gels with CP involves the slow and gradual release of low H_2O_2 concentrations into the tooth structure. For the bleaching to be effective, the product must be applied daily for 1–8 h, over relatively long periods (1–4 weeks), to achieve the desired esthetic effect. This technique is not performed in the dental office but at the patient's home, where the patient can apply the bleaching gel using custom-fitted vinyl acetate trays.

Gingival irritation associated with supervised at-home bleaching is related to two key factors, namely, (1) trauma from the tray and (2) the toxic effect of the gel on the oral mucosa. The first step to prevent trauma to gingival tissues during at-home bleaching is the use of trays custom-made by a dental professional. Prefabricated trays used in OTC bleaching regimens do not offer adequate adaptation and can expose the oral mucosa to contact with the bleaching product. It is worth noting that the tray may cause trauma due to flaws in the model or inadequate trimming of the tray even when the treatment is supervised by a dental professional. The practitioner must identify the compression areas during tray try-in to prevent this adverse event. In fact, ill-fitting trays may potentially result in traumatic ulcerative lesions, which may result in severe discomfort for the patients (Matis 2003).

Once the possibility of mechanical trauma to gingival tissue caused by the tray is ruled out efforts should be directed to retaining the gel inside the tray throughout the treatment, reducing the possibility of leakage of the product and consequent contact with adjacent soft tissues. In vitro studies have determined that low H_2O_2 concentrations (3%) exert a cytotoxic effect on gingival fibroblasts and negatively affect proliferative capacity, fibronectin expression, and type I collagen (Tipton et al. 1995; Oda et al. 2001). Animal studies have shown that the topical application of 10% CP to the tongue of rats for 20 min once a week for 3 weeks promoted epithelial changes characterized by increased cell proliferation of the basal layer, which was transient and reversible 10 days after the procedure (Albuquerque et al. 2002). This demonstrates that even low H_2O_2 concentrations can have a toxic effect when in direct contact with oral mucosa cells.

Several alternatives have been discussed in relation to the design of the tray that can prevent leakage of the bleaching gel to soft tissue regions. The trimming of the tray at gingival level or scalloped tray has proven to be an effective measure to prevent the flow of product beyond the cervical tooth region (Matis 2003). For this reason, it is suggested that the tray does not extend to the gingival tissue, preventing its compression while minimizing the possibility of direct contact of the bleaching product with gingival tissue. The appropriate volume of bleaching gel to be applied to the tray is equivalent to only one drop for each tooth to be bleached. This amount of product is sufficient for the gel to maintain contact with the entire tooth surface and optimize its effect. The product must be removed with a cotton pellet or a toothbrush in case any excess extrudes from the tray. The use of reservoirs on the buccal surface of the tray does not promote an increase in bleaching effectiveness and results in a greater amount of H_2O_2 detectable in saliva (Matis et al. 2002; Matis 2003) (please refer to Chap. 6 for more details). Thus, we should avoid adding space for reservoirs to the stone model during tray fabrication, which results in better adaptation of the tray to the teeth to be bleached and less leakage of the bleaching gel. Figure 4.1 shows the gingival positioning of scalloped trays in comparison with that of traditional trays.

In a clinical study conducted by Leonard et al. (2001), bleaching with 10% CP gel in scalloped trays applied daily (6–8 h) for 14 days showed minimal adverse effects on oral soft tissues. The authors conducted an analysis of the marginal (gingival index) and non-marginal gingiva (non-marginal gingival index) and the possible changes in non-gingival soft tissues (non-gingival oral mucosal index) after 7 and 14 days of treatment. They did not observe any significant differences in all the parameters tested between the bleached and non-bleached groups. Only 8% of the patients reported gingival irritation during the treatment course, and none of them reported gingival irritation during 3, 6, and 47 months posttreatment. These results corroborate the findings of the study by Almeida et al. (2015) that the application (2 h/day) of bleaching gels containing 10% and 16% CP in scalloped trays for 21 days did not cause genotoxicity in the adjacent gingival tissue to the teeth subjected to bleaching. In pre- and post-bleaching analyses, Firat et al. (2011) observed that the application of an at-home gel with a high CP concentration (35%) in trays with gingival trimming for 15 days (30 min/day) caused no changes in clinical

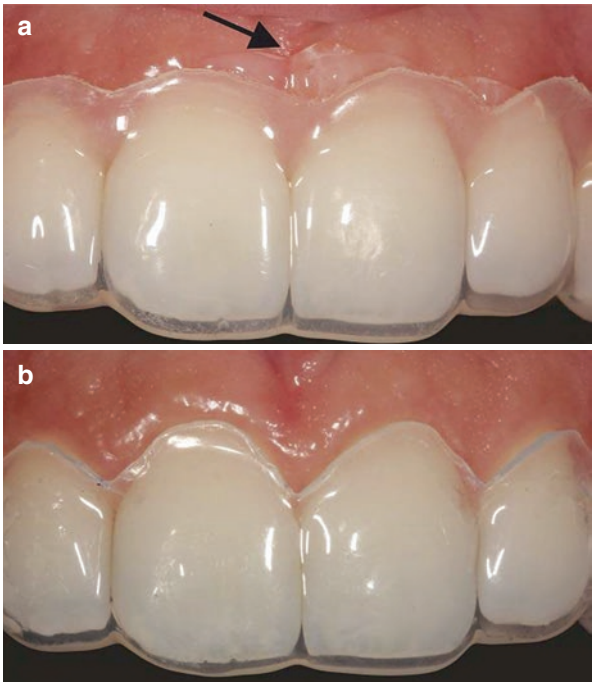

Fig. 4.1 (**a**) Traditional tray showing the possibility of direct contact of the bleaching gel with soft tissue. (**b**) The scalloped tray that keeps the bleaching gel in contact exclusively with the enamel tissue

parameters for the gingiva and periodontium and increases in the levels of pro-inflammatory cytokines in crevicular fluid. Several clinical studies reported that contact of at-home gels with oral tissues resulted in inflammation and erosion of the marginal gingiva, as well as cervical resorption and gingival recession, which contraindicate the contact of the products with the marginal gingiva for long periods (Powell and Bales 1991; Haywood et al. 1997). da Costa Filho et al. (2002) performed a gingival tissue biopsy in smokers and nonsmokers who underwent treatment with a gel containing 10% CP, applied for 8 h per day for a period of 5 weeks. Biopsies performed immediately after the bleaching treatment revealed an increase in epithelial thickness and cell proliferation to basal and parabasal layers, resulting in morphometric changes of the gingival tissue, when compared with biopsies performed 15 days before the bleaching treatment. The results were similar between the smokers and nonsmokers. In the abovementioned clinical studies, bleaching trays without gingival trimming and reservoirs in the vestibular region were used.

The possibility of daily contact of H_2O_2-rich bleaching agents with oral tissues remains controversial. Several studies showed that high concentrations of H_2O_2 may cause cancer in the duodenum and jejunum of rats treated concomitantly with carcinogens. However, the administration of H_2O_2 alone did not lead to the development of lesions in these tissues (Naik et al. 2006; Minoux and Serfaty 2008; Paula et al. 2015). According to the results reported by Hannig et al. (2003), only 1.25% H_2O_2 present in the gel with 10% CP was detected in saliva from patients who

underwent bleaching in conventional custom-made trays with a 1.5-mm reservoir, with the highest release observed within the first 5 min. Thus, the systemic effects of H_2O_2 derived from at-home bleaching are still considered quite controversial (Naik et al. 2006; Minoux and Serfaty 2008). It is noteworthy that a cocarcinogen agent does not start mutations alone but requires an initiator of neoplasia in the oral cavity. Such a clinical condition is a contraindication for carrying out esthetic treatment. Still, we believe that treatment should be performed by a qualified professional able to diagnose changes in hard and soft tissues during the early phase of the treatment. In this sense, the OTC availability of products for home at-bleaching, including topical application of the bleaching agent to the teeth with prefilled disposable trays, compromises the safety of tooth bleaching.

Regarding the concentration and form of the at-home bleaching gel, few studies are available in the literature related to the effects of pure H_2O_2-based home gels on soft tissues. Several studies showed that the amount of H_2O_2 in saliva is proportional to the H_2O_2 concentration in bleaching gels and that the use of CP-based gels results in lower amount of H_2O_2 in saliva than products containing pure H_2O_2 (Hannig et al. 2003, 2005). The degradation of 10% CP in H_2O_2 has been demonstrated to occur primarily in the first hour after bleaching, and this degradation occurs primarily in the region of product contact with the tooth surface (Matis et al. 1999). Concurring with these results, the findings of clinical and laboratory studies demonstrated that the same bleaching pattern can be obtained when the gel with 10% CP is applied either over short periods (1–4 h) or during traditional night use for 8–10 h (de Almeida et al. 2015). Furthermore, the same bleaching effectiveness was observed after treatment between the 10% CP gel and the 16–20% CP gels, as well as pure H_2O_2-based gels (Meireles et al. 2010; Basting et al. 2012; Almeida et al. 2015). Thus, we believe that 10% CP is still the safest product to use in supervised at-home bleaching owing to the positive results described in several studies that evaluated this particular concentration of CP.

We can therefore conclude that direct contact of bleaching gels with gingival and periodontal tissues should be avoided in order to eliminate the possibility of tissue damage mediated by H_2O_2. The application of a minimum amount of bleaching gel (enough to cover only the vestibular surface of the teeth) in an individualized tray with trimming at the gingival level and without reservoir promotes effective tooth bleaching with minimal damage to oral soft and/or pulp tissue. Furthermore, in order to prevent inadvertent swallowing of bleaching product residues, home bleaching with the use of gels with 10% CP, applied for a maximum period of 1–3 h on teeth, has been recommended.

4.2.2 OTC Products

Currently, another type of tooth bleaching treatment, which involves the use of OTC products, has become popular. OTC products can be bought in pharmacies, supermarkets, or even over the Internet and are used without dentist supervision. These products emerged in the United States about 15-20 years ago as an alternative

treatment for stained teeth, with lower cost than traditional supervised treatment (Demarco et al. 2009). The active component is the same as that in traditional bleaching agents, that is, either CP (10% to 22%) or H_2O_2 (1.5 to 14%), which is available in various forms such as bleaching strips, varnishes, gels, paint-on liquids, mouthwashes, and toothpastes. However, these products offer no protection to soft tissue adjacent to the teeth subjected to bleaching. As such, their indiscriminate use without professional guidance raises concerns about the possible adverse effects (Demarco et al. 2009).

Universal trays and bleaching gels, even those administered with lights and electrodes, are available online. Poor adaptation of the tray certainly permits the flow of the material to the oral cavity, resulting in contact of a large amount of product with the oral mucous membrane and possible swallowing of high concentrations of toxic components. Few clinical studies have been conducted with these materials, but many of these studies were sponsored by the manufacturers of these materials. In a recent report, an OTC product was applied in areas of gingival recession (Ghalili et al. 2014), a procedure contraindicated especially when using prefabricated trays. Studies that used varnishes and paint-on liquids showed that these products do not promote effective bleaching of the tooth surface (Kishta-Derani et al. 2007; Lo et al. 2007). We therefore consider that these materials, apart from having poor esthetic effectiveness, may also cause some risk to the health of consumers.

Among the OTC bleaching products, bleaching strips are the most popular products owing to their clinically noticeable esthetic effects, making them superior to the other products of the same category (Xu et al. 2007; Yudhira et al. 2007; Kwon et al. 2013). These products were created to eliminate the use of trays, with a thin layer of H_2O_2 added to the adhesive surface, which is released in relatively short periods (5–60 min). A systematic literature review demonstrated that the esthetic effectiveness of bleaching strips was similar to that observed for the bleaching protocol recommended by the ADA (10% CP) and that the adverse effects were similar when the two types of bleaching treatment were compared. However, serious questions in the literature remain to be answered regarding the true efficacy and safety of these products (Demarco et al. 2009). According to Hasson et al. (2006), most clinical trials of bleaching strips were biased, primarily because of the short period of post-treatment evaluation.

Bleaching gels with 10% CP have only 3.5% H_2O_2 in their composition, about half of the H_2O_2 concentration found in the less-concentrated strips. Clinical studies demonstrated that the H_2O_2 concentrations in the saliva of patients who underwent bleaching with bleaching strips (5.3% H_2O_2) are about two to four times higher than those observed for 10% and 15% CP gels applied in custom-made trays (Hannig et al. 2003, 2005). The main question regarding the safety of the use of these products is related to the absence of protection of the gingival tissues. As the bleaching strips have a predefined shape, contact of the H_2O_2-rich surface with the gingival papilla occurs during treatment. As discussed previously, adverse effects on gingival and periodontal tissues are expected. The extent of these effects may lead to the development of side effects especially because the products are applied without dentist supervision, which may lead to its indiscriminate use.

In an interesting study by Auschill et al. (2012), the bleaching efficacy and biological effects on soft tissues provided by bleaching agents with similar H_2O_2 concentrations were evaluated. However, the products were applied according to the supervised at-home technique or by using a bleaching strip. Patients were instructed to use a home bleaching gel containing 5% H_2O_2 in a scalloped tray with a 1.0-mm reservoir or to apply a bleaching strip containing 5.3% H_2O_2, without any method of protection of soft tissues, as recommended by manufacturers. Both products were applied twice a day for 30 min during the 14-day period. The bleaching efficacy during, at the end, and 18 months after the treatment was statistically similar for both products. However, 40% of the patients who used the bleaching strip reported gum irritation, while only 20% of patients who underwent bleaching with a tray reported the development of this adverse effect. Tooth sensitivity was also more prevalent in the patients who used a bleaching strip (60%) than in those who used a gel in the tray (47%). The adverse effects were considered mild and transient in both groups. Considering both biological factors (gum irritation and tooth sensitivity), the percentage of discomfort during bleaching was higher for the patients who underwent bleaching with bleaching strips.

Other clinical studies showed that the percentage of tooth sensitivity and gum irritation are proportional to the H_2O_2 concentration in bleaching strips, the contact time with product, and the total treatment time (Kugel et al. 2011; Donly et al. 2010). According to the data obtained by Swift Jr et al. (2009), about 80% of gum irritation cases occurred after long treatment periods in patients who used bleaching strips. In a study conducted by Lucier et al. (2013), the toxic effect of bleaching strips containing different H_2O_2 (6–14%) concentrations was evaluated on the gingival epithelium in vitro in a three-dimensional culture model. The authors observed changes in tissue morphology that were associated with the apoptotic death of cells in all epithelial layers, induced keratinocyte proliferation, and increased expression levels of proinflammatory cytokines. These effects were proportional to the H_2O_2 concentration in bleaching products.

It is worth emphasizing that the presence of cracks, exposed dentin, changes in enamel, caries lesions, wear facets, abfractions, restorations with infiltration, gingival recession, gingivitis, and periodontal disease can influence the extent of the harmful effects of bleaching products on oral and pulp tissues. However, these negative effects caused by bleaching agents applied in specific clinical situations have been rarely studied. By contrast, several studies have evaluated the esthetic effectiveness of bleaching products and techniques. Thus, the dentist should perform a careful analysis before beginning the bleaching treatment to determine the optimal treatment for each case. Therefore, the use of products containing H_2O_2 for tooth bleaching without professional supervision represents a health risk to the population who is unaware of the factors involved with the use of such products and the conditions of their oral health. Regulatory bodies in Brazil and in the European Union have already restricted the commercialization of bleaching products to dentists to protect the population from the risks of using bleaching agents without professional supervision (please refer to Chap. 6). However, in several countries, including the United States, such products are still accessible to the general population and have

great economic impact owing to the strong esthetic appeal involved (Demarco et al. 2009).

4.2.3 In-Office Bleaching

It is well established that once the in-office technique is chosen, all oral soft tissues, as well as the face and eyes of patients, must be protected from accidental contact with the bleaching products. Clinical studies where qualified practitioners perform the entire bleaching procedure reported a percentage of 0–4% of patients with mild to moderate gum irritation, irrespective of the H_2O_2 concentration used (Marson et al. 2008; Ward and Felix 2012). This result is expected, as the placement of a suitable gingival barrier with low-viscosity light-cured resin effectively prevents the contact of the bleaching gel with the gingival and periodontal tissues. However, the gingival barrier must be applied carefully, and it must extend to the cervical region of the teeth to be bleached and to the adjacent region to prevent inadvertent contact with the bleaching product. Associated with the gingival barrier, retractors and labial and lingual protectors should be used with constant suction. Figure 4.2 demonstrates the correct use of light-cured gingival barriers and intraoral protective equipment in the in-office bleaching. This equipment will prevent the contact of the bleaching agent with other

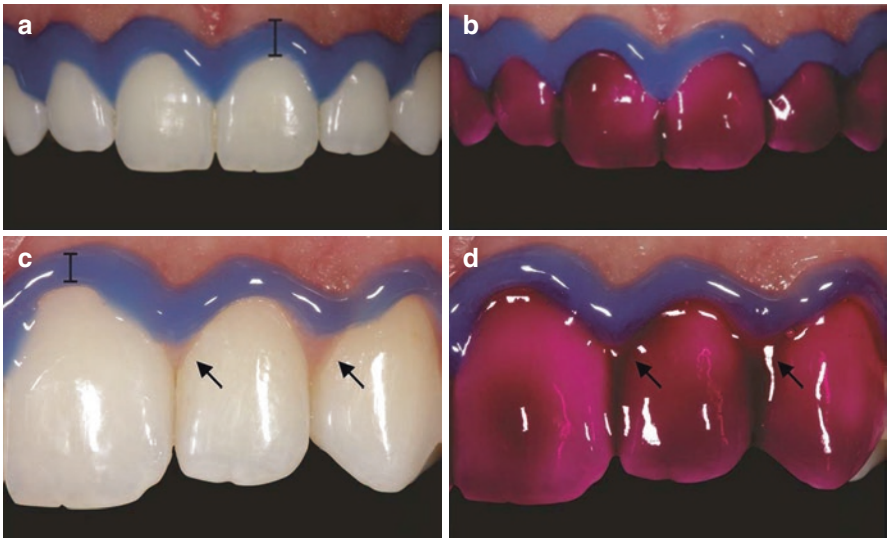

Fig. 4.2 (**a**) Correct use of the gingival barrier, carefully positioned around the cervical region covering the interdental papilla and a considerable portion of the marginal gingiva. (**b**) Correct application of bleaching gel minimizing the possibility of any undesirable incident with the product. (**c**) Deficient application of the gingival barrier that did not adequately protect the soft tissue. The barrier was not extended enough into the soft tissue and gingival papilla. (**d**) A common incident during the in-office bleaching procedure showing the gel in contact with the soft tissues (the photo was exposed with a placebo bleaching gel without H_2O_2)

oral tissues caused by inadvertent movements of the patient. At the end of the application period, the gel must be carefully suctioned from the tooth surface, followed by rinsing with simultaneous suction, to prevent the flow of highly concentrated H_2O_2 to the oral cavity and the ingestion of product residue by the patient (Fig. 4.2).

However, quite often, gingival barriers are positioned inadequately or are moved during the procedure, allowing direct contact of highly concentrated peroxides with the adjacent gingival tissue. When such accidents occur, the mucosa turns temporarily white, but is likely to return to normal after the application of a neutralizing agent and local rehydration. These effects are observed in Figs. 4.3, 4.4, and 4.5.

During prolonged contact with the oral mucosa significant epithelial alteration associated with acute inflammation of the underlying connective tissue may occur. These pathological changes are caused by incorrectly performing the bleaching procedure and may cause discomfort of the patient. The severity of the damage to the mucosa can be directly related to the concentration of H_2O_2 present and/or released by the bleaching product, its pH, and the time of contact of the gel with the tissue. In an ongoing in vivo study by our research group, the oral mucosa of rats is exposed to the application of different bleaching gels for 30 min. Then, biopsy samples of damaged tissues treated or untreated with a neutralizing agent (sodium bicarbonate) are obtained and processed for microscopic analysis of tissue response. Preliminary analysis of histological sections stained with hematoxylin and eosin revealed that the extent of tissue changes varied according to the applied bleaching product and

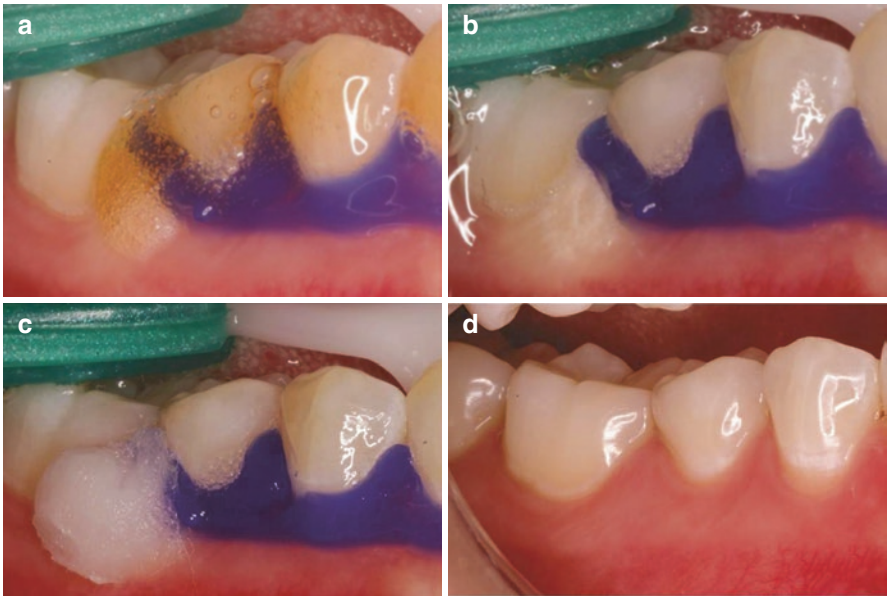

Fig. 4.3 (**a**) The bleaching gel flowing to the area not protected by the gingival barrier. (**b**) Clinical characteristic of the gingival tissue immediately after contact with the bleaching gel. (**c**) Application of a neutralizing agent. (**d**) Clinical aspect of the gingival tissue 7 days after the accident

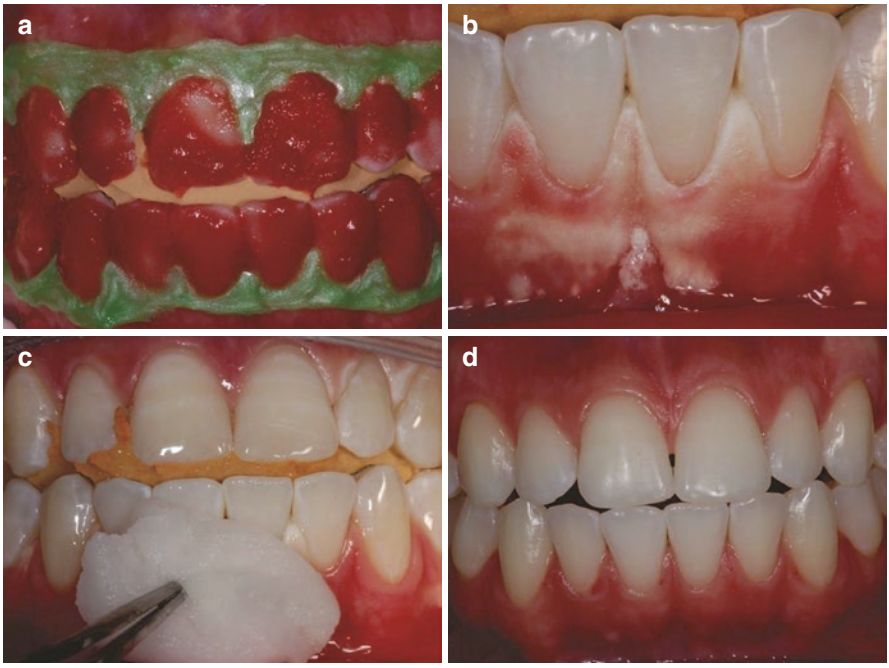

Fig. 4.4 (**a**) Lower incisors submitted to in-office bleaching. (**b**) The barrier may have been applied in an excessively humid operative field, or the gel may have kept in the mouth for too long which could have caused alterations in the thixotropic characteristics of the gel and subsequent seepage to the soft tissue, causing extensive damage. (**c**) Application of neutralizing product based on sodium bicarbonate. (**d**) Clinical aspect 45 min after the incident

that etching of the damaged mucosa with a neutralizing agent reduces the extent of damage caused by the bleaching gels, particularly those with H_2O_2 concentrations greater than 15% (Fig. 4.6).

Another factor that may be related to gingival tissue aggression is the site of application of whitening gel. As shown in Fig. 4.2, the isolation of gingival tissue is sometimes ineffective, with areas of exposure to the soft tissues, especially around the dental papillae. This region is the most cervical portion of the crown, which sometimes comes into contact with a large volume of whitening gel. The preponderant dentin component in this region of the tooth means that it is a region very relevant for any changes in tooth color.

A possible strategy to minimize the risk of gingival tissue burns under these clinical conditions is to reduce the area of exposed crown to ensure that the bleaching gel is not applied in areas close to the gingival tissue. Haywood and Heymann (1991) reported that H_2O_2 diffuses very well through the tooth structure and is present not only in the applied area but also in the entire tooth structure. However, the clinical evidence is not abundant (Gomes et al. 2017; Jadad et al. 2011).

To illustrate the bleaching capacity and remote action of the bleaching gel, clinical cases (Figs. 4.7, 4.8, and 4.9) evaluated the chromatic alteration capacity in

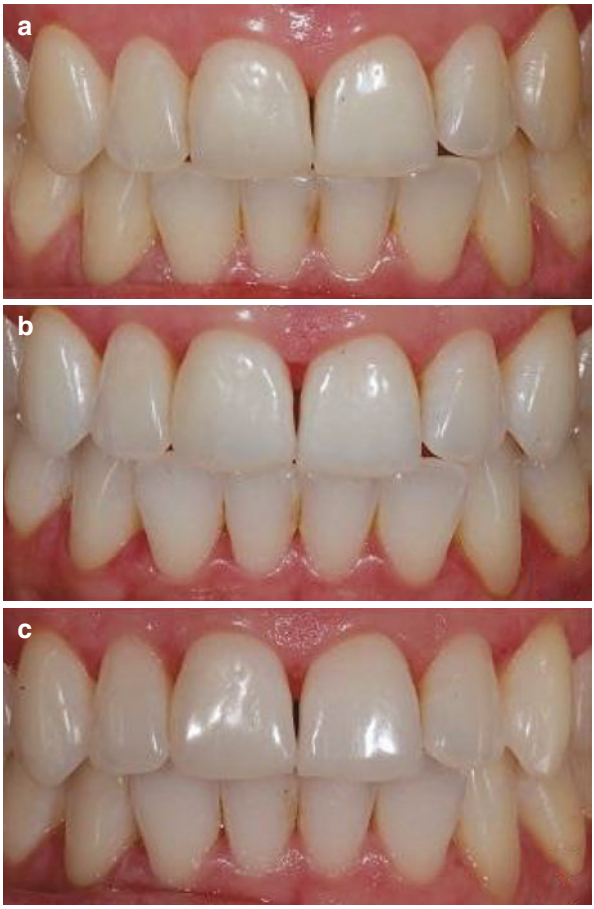

Fig. 4.5 Effect of the bleaching treatment on the gingival papilla region after the "jump-start" technique (association of at-home and in-office technique). We considered the possibility of allergic reaction to components of the bleaching product, since there was no compression of the tray in the papillae regions. (**a**) Clinical characteristic before bleaching. (**b**) After removing the bleaching agent and gingival barrier, the retraction of the gingival papilla associated with an erythematous surface is observed between teeth #6 (FDI 1.3) and #9 (FDI 2.1); (**c**) Clinical aspect after 7 days

different regions of the clinical crown. The patients underwent an in-office bleaching treatment with 35% H_2O_2 gel without any source of physical activation. The whitening gel applied to the entire crown or the application area was limited. Three clinical sessions were performed with the gel remaining in contact with the area of interest for 45 min.

In Fig. 4.7, the baseline color of incisors and canines was VITA A3. On the right hemiarch the gel was applied to the cervical half of the crown, while on the left hemiarch the gel was applied to the entire surface of the tooth (Fig. 4.7).

In Fig. 4.8, the maxillary anterior teeth of the right hemiarch were bleached on the incisal half, while on the left hemiarch the gel was applied to the entire buccal surface.

In Fig. 4.9, the maxillary anterior teeth of the right hemiarch were bleached on the cervical half, while on the left hemiarch the gel was applied to the incisal half.

The chromatic changes of the teeth in the reported cases were analyzed quantitatively using a portable spectrophotometer in the cervical and incisal regions of the

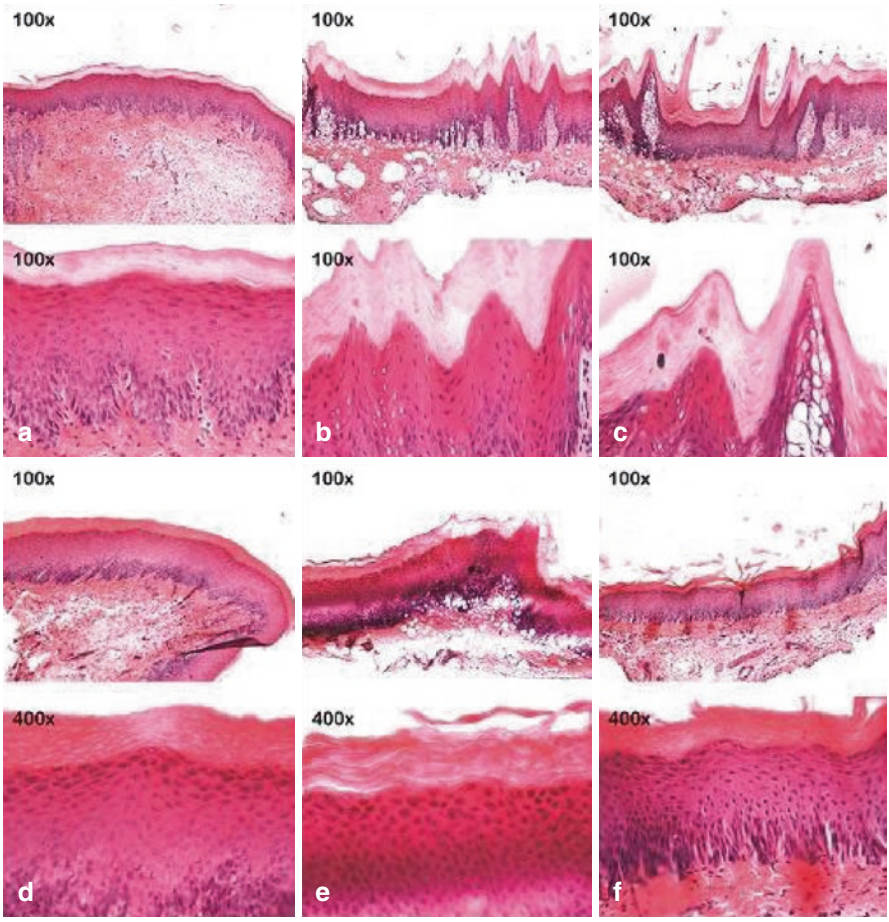

Fig. 4.6 (**a** and **d**) Bleaching gels are applied to the buccal mucosa of rats for 30 min followed by treatment or no treatment of the injured tissue with a neutralizing agent (sodium bicarbonate). The mucosa exposed to 10% CP gel does not show any notable change in the epithelium and underlying connective tissue. However, the epithelium treated with gels containing 15% (**b** and **e**) or 35% H_2O_2 (**c** and **f**) shows numerous fingerlike papillae, acanthosis, and large areas of cell vacuolation. Intense inflammation associated with cell hydropic degeneration and extensive areas of edema can be observed in the underlying connective tissue. However, these tissue changes appeared less intense when the mucosa of the animals exposed to these gels with high H_2O_2 concentrations was subsequently treated with a neutralizing agent

crown throughout the treatment. The data were evaluated against the limits of acceptability and perceptibility proposed by Paravina et al. (2019), who determined the value of 1.2 as the limit of perceptibility (ability to perceive a difference between two values) and 2.7 as the limit of acceptability (difference considered clinically unacceptable).

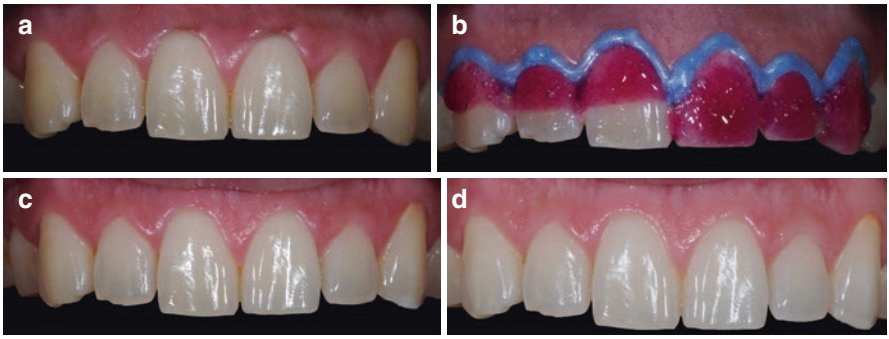

Fig. 4.7 (**a**) Treatment performed with application of bleaching gel in the cervical region vs. on the entire buccal surface. The baseline color of incisors and canines was VITA A3. (**b**) Different application protocols for the whitening gel. (**c**) Clinical aspect after the first session. (**d**) Clinical aspect after three sessions. The color changes were homogeneous regardless of the gel application protocol – cervical region or entire surface

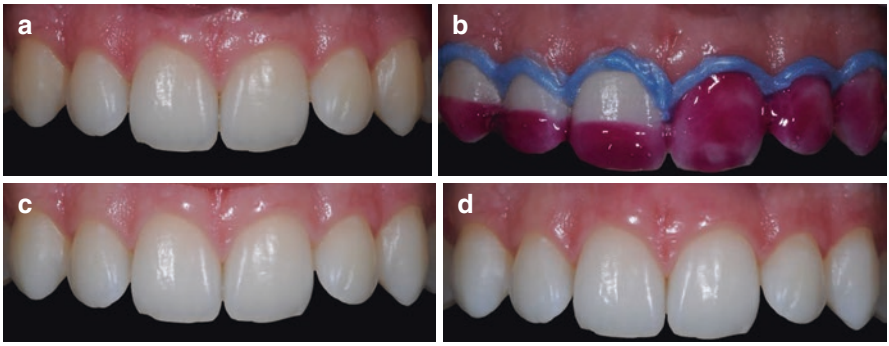

Fig. 4.8 (**a**) Application of bleaching gel on the incisal region vs. on the entire buccal surface. Baseline color was VITA A2. (**b**) Different application protocols for the whitening gel. (**c**) Clinical aspect after the first session. (**d**) Clinical aspect after three sessions. The color changes were homogeneous regardless of the gel application protocol – incisal region or entire surface

Of all the patients submitted to the treatments in the clinical cases depicted above, only the case in Fig. 4.9 (cervical x incisal) presented perceptible but acceptable differences in the cervical region between the hemiarches after the third bleaching session.

In the incisal region, the cases presented in Figs. 4.7 and 4.9 had values above perceptibility in T1 and T2; however, in subsequent evaluations, only the case in Fig. 4.9 retained perceptible but acceptable changes.

Overall, even in the three cases with notable differences in the initial phase of treatment, the response tended to be homogeneous at the end of the three bleaching sessions, with chromatic results favorable to the patient. The evaluation of these data in Fig. 4.10 compares the limits of perceptibility and acceptability with the ΔE

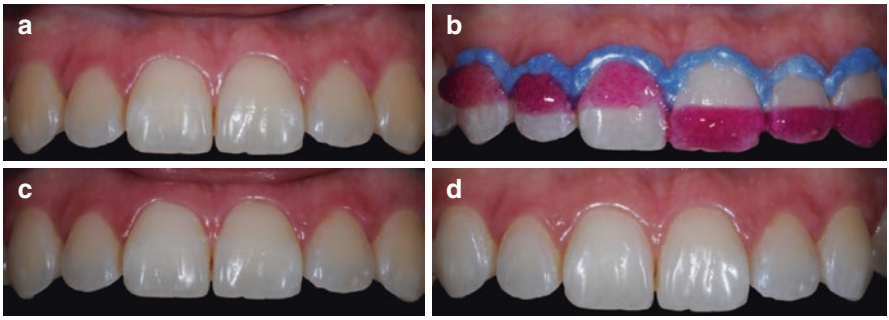

Fig. 4.9 (**a**) Application of bleaching gel on the cervical region vs. on the incisal region. Baseline color was VITA A2. (**b**) Different application protocols for the whitening gel. (**c**) Clinical aspect after the first session. (**d**) Final result. The color changes were homogeneous regardless of the gel application protocol – incisal region or entire surface

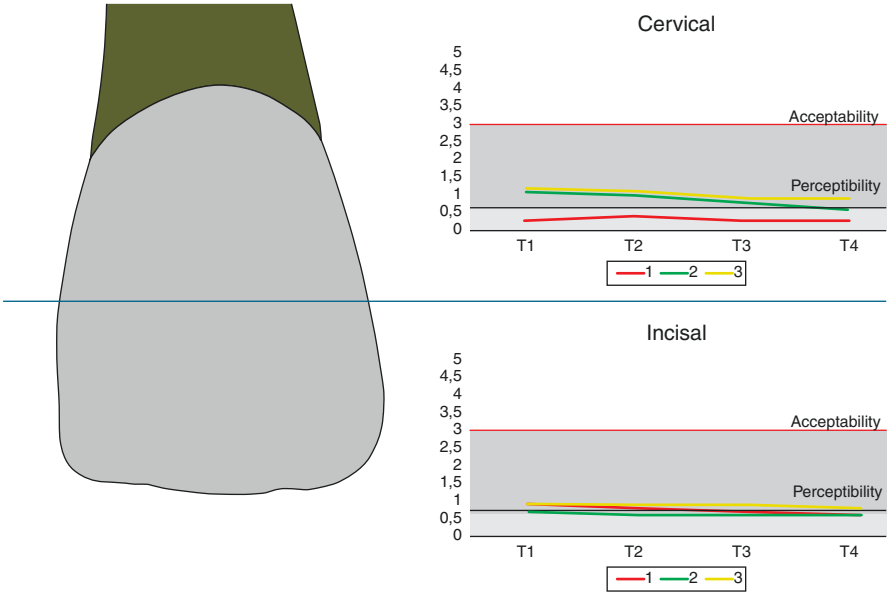

Fig. 4.10 Each line represents the difference in the ΔE values obtained for each hemiarch. Comparison of the perceptibility and acceptability limits with the ΔE values obtained in the cervical and incisal regions between the hemiarches (red line, application on the entire vestibular face vs. on the cervical (Fig. 4.7); green line, application on the incisal application vs. throughout the buccal face (Fig. 4.8); yellow line, cervical application vs. incisal application (Fig. 4.9) in function of time)

values obtained in the cervical and incisal regions between the hemiarches in function of time.

In line with these findings, Esteves et al. (2022a, b) stated that the diffusion of peroxide and other reactive oxygen substances occurs quickly in a multidirectional

manner and does not depend solely on the main orientation of the diffusion pathways, represented by porosities in the enamel interprismatic region. This diffusion is facilitated by the low molecular weight of reactive oxygen species (ROS), which also confers them the ability to seep across secondary intertubular porosities, resulting in significant chromatic changes in regions of the tooth that did not come into contact with the ROS. These chromatic changes were identical to those in which the tooth maintained direct contact with the gel (Esteves et al. 2022a; Kwon et al. 2013; Kugel et al. 2011). It was further observed that patients who received the gel in the cervical portion reported more significant discomfort during bleaching, while patients who received the gel in the incisal portion or the entire buccal surface did not report any discomfort. This finding can be explained by reduced thickness of the enamel in the cervical region that may have favored the rapid diffusion of ROS to the dentin-pulp complex.

The bleaching treatment can be optimized by controlling the application surface area and by avoiding the most cervical region. These two measures reduce the risk of tooth sensitivity and potential soft tissue lesions, leading to patient satisfaction in addition to a better esthetic outcome.

4.3 Effect on Oral Hard Tissues

4.3.1 Change in Color of Tooth Structure

Tooth bleaching has been the first choice of treatment for intrinsic pigmentation of tooth structure (Williams et al. 1992; Perdigão 2010). The bleaching process is believed to occur via the action of the low-molecular-weight H_2O_2 (Chap. 2). Peroxides diffuse easily through the enamel and dentin releasing ROS, which effectively promote the oxidation of the organic substrate in the tooth structure. As a result, the complex molecules responsible for dental pigmentation are converted into simpler molecules or are eliminated (Chap. 2). Although the traditional in-office bleaching technique (30–40% H_2O_2, applied for 30–60 min) provides very satisfactory cosmetic results in a short period, the biological effects of this therapy are controversial because of the scientific evidence showing the potential for irreversible damage to the pulp-dentin complex. Moreover, the intense tooth sensitivity in patients treated with in-office bleaching causes great discomfort to patients, which has led researchers to review the concepts used in the last decades.

Our research group has evaluated some parameters for the application of the at-home and in-office bleaching with the aim of finding more effective and more biocompatible bleaching techniques. These parameters include (1) the need for irradiation of the in-office bleaching gel with light, (2) the H_2O_2 concentration in bleaching gels, (3) the contact time of the product with the tooth surface, (4) the need for reapplication of the gel on the tooth surface during the same clinical session, (5) the form of the bleaching gel (CP versus H_2O_2), (6) combined use of at-home and in-office bleaching, and (7) and the need for acid etching of the enamel prior to bleaching.

The irradiation of in-office bleaching agents with light has had a strong commercial appeal in recent decades. It has been widely used in dental offices to accelerate the bleaching procedure, a technique known as power bleaching. The action mechanism proposed for irradiation with light is based on thermocatalysis, resulting in a twofold increase in H_2O_2 decomposition with a temperature increase of 10 °C (Buchalla and Attin 2007). However, the real benefits of bleaching activated by light remain controversial in the peer-reviewed literature. According to the results obtained in in vivo and in vitro studies conducted by our group, irradiation of the bleaching gel with 35% H_2O_2 by using halogen lamps (20–40 sec/application) and LED (60 sec/application) or LED/laser sources (3 min/application) did not promote a significant increase in the bleaching effect from the first bleaching session up to 1–6 months after bleaching. Patients who underwent bleaching with light irradiation reported a longer duration and greater intensity of tooth sensitivity (Briso et al. 2012; Almeida et al. 2012; Simões et al. 2015). Based on these findings, the use of traditional in-office gels in combination with light sources should be eliminated from everyday practice.

In relation to the concentration of H_2O_2 used in the in-office technique, in vitro studies that used ultraviolet reflection spectrophotometers showed that the color change is saturated after three or four sessions when 35% H_2O_2 gels were used, with about 50–60% of the total color change obtained after the first bleaching session (Briso et al. 2012; Soares et al. 2014a, b; de Almeida et al. 2015). By using non-stained specimens with external pigments, these authors observed that a gel with 20% H_2O_2 showed the same bleaching behavior as a gel with 35% H_2O_2; this means that about 60% of the color change occurred after the first bleaching session, based on the similar color change pattern observed after the second and third sessions (de Almeida et al. 2015). When specimens stained with black tea (yellow pigment) were used, a gel with 17.5% H_2O_2 promoted a gradual color change in the tooth structure. While a more concentrated gel (35% H_2O_2) caused 50% of the color change after the first session, a gel with 17.5% H_2O_2 promoted about 36.5% of color change, with the bleaching being intensified throughout the sessions so that no difference with the traditional protocol was observed at the end of four sessions (Soares et al. 2014a, b). It is noteworthy that the results described earlier refer to the same duration of full contact with the tooth structure (45 min). The advantage of using lower concentration gels lies in the fact that these products minimize H_2O_2 diffusion over the tooth structure by about 60%, which has a positive biological effect on pulp cells and confers less risk to the oral mucosa. In order to corroborate the data obtained by our group, Sulieman et al. (2004) observed that bleaching efficacy was proportional to the concentration of the bleaching agent applied on teeth darkened with black tea. It took 2, 4, 7, and 12 applications for the gels containing 25%, 15%, 10%, and 5% H_2O_2, respectively, to obtain the same bleaching effect observed after a single application of the gel containing 35% H_2O_2. Thus, gels with reduced H_2O_2 concentration can reach the same bleaching standard attained for traditional gels with high H_2O_2 concentrations, but slower and more gradually, depending on the intrinsic staining intensity of teeth under treatment.

Similar results were obtained for the at-home bleaching technique. Gels with 16% and 20% CP were observed to have the same bleaching potential as the gel with 10% CP, with the latter resulting in lower tooth sensitivity and less soft tissue irritation (Meireles et al. 2010; Basting et al. 2012). When comparing CP with H_2O_2, we observed that home bleaching gels with 10% CP have the same bleaching potential as home bleaching gels with 6% H_2O_2 when applied over the same treatment duration (1.5 h/day for 3 weeks). However, the H_2O_2-based gel resulted in H_2O_2 diffusion over the tooth structure at about 50% greater intensity. Furthermore, the application of the product with 10% CP for 1.5–3 h resulted in the same esthetic effect after 7, 14, and 21 days of treatment. The shorter the contact time, the lower the H_2O_2 trans-amelo-dentinal diffusion (Almeida et al. 2015). Home treatment with gels containing 10% CP, applied for 3–4 h a day for 3 weeks, was observed to have the same bleaching potential as traditional in-office bleaching (Briso et al. 2012; Almeida et al. 2012; Basting et al. 2012).

Fig. 4.11 contains data from our laboratory and clinical trials. According to these results, the at-home bleaching technique using either CP (10–16%) or H_2O_2 (3–7%) and the in-office technique (20–40% H_2O_2) most often provide similar results at the end of the third week of treatment, reaching the chromatic saturation in most cases within this period. We also found that the combination of at-home and in-office techniques (jump-start) provides a faster color change at the beginning of treatment, which makes this an interesting option to accelerate the esthetic result. We suggest that the association of in-office bleaching sessions with low H_2O_2 concentrations (15–20%) followed by daily at-home applications of 10% CP bleaching gel over a short period (1.5 h/day) in a scalloped tray without reservoirs presents itself as a viable alternative to accelerate the esthetic result by using a more biologically friendly bleaching

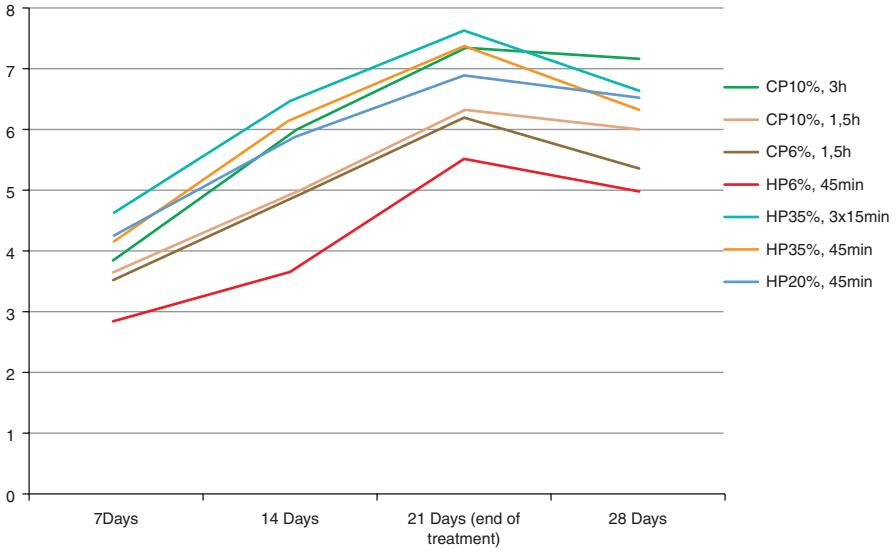

Fig. 4.11 Color change (Delta E), according to bleaching dosage employed and treatment time

technique. However, practitioners need to be aware that the indication of the at-home technique should be based on a detailed initial clinical examination to avoid the application of the material in areas that may increase the toxic potential of this bleaching regimen. These precautions will be discussed later in this chapter.

The need for multiple applications of the bleaching product during the same clinical session has also been questioned. In a recent study, we observed that bleaching gels with 35–38% H_2O_2 retain about 86% of the initial concentration of H_2O_2 after 45 min of contact with the tooth structure. These results demonstrate that reapplication of the bleaching product during in-office bleaching is not necessary (Marson et al. 2015). In the study by de Almeida et al. (2015), a gel with 35% H_2O_2 showed the same bleaching potential when applied once for 45 min or three times for 15 min each on the tooth surface, and the single application of the product did not cause biological damage. Similarly, Soares et al. (2014a, b) found that the continuous application of a gel with 17.5% H_2O_2 for 15 min or reapplication of the product three times for 5 min each resulted in the same esthetic effects in six whitening sessions. The application of the in-office bleaching product on the tooth structure over reduced periods promotes gradual and effective bleaching when bleaching gels with 35% H_2O_2 were tested (Soares et al. 2014a, b). However, application of gels with lower H_2O_2 concentrations on the tooth structure over short periods (5–15 min) resulted in a less pronounced color change, even after six bleaching sessions (Soares et al. 2014a, b).

Finally, acid etching of the tooth structure prior to in-office bleaching has been recommended in order to increase its effectiveness. Recently we carried out a research project in which enamel was etched with 37% phosphoric acid for 20 seconds, immediately prior to the application of the bleaching gel with 35% H_2O_2 (three times for 15 min each). Enamel etching did not result in a significant increase in bleaching effectiveness nor did it interfere with H_2O_2 diffusion over the tooth structure. Enamel etching is contraindicated prior to bleaching because it induces changes in the mineral structure of the enamel, which are already increased as a result of the application of the bleaching gel.

4.3.2 Microabrasion and Tooth Bleaching

In some cases, residual stains are still observed on the enamel after completion of the bleaching treatment. While there are several types of stains, we found that these are whitish and usually have well-defined contours. Some of these stains can be transient and become imperceptible with the color stabilization and rehydration of the tooth after bleaching. Often, these stained areas already existed but only became apparent after the color change from the bleaching treatment. On the other hand, such stains become attenuated or even invisible after tooth bleaching in patients who present with yellow teeth with enamel whitish stains. In any case, patients should be informed of the possibility of residual stains. Considering the texture or color changes of the surface layers of enamel, microabrasion of dental enamel has been suggested as an excellent alternative to improve the appearance of the teeth.

Although several studies have shown that the removal of tooth surface is minimal with microabrasion, it is necessary to consider that these changes reach different depths and that the aprismatic enamel layer can also be affected. It is important to note that the microabrasion products contain HCl and abrasive products which can substantially alter the permeability of dental tissues. This is especially pertinent when the bleaching treatment is indicated immediately after the microabrasion, as the H_2O_2 diffusion over the tooth structure in these conditions is about 20% higher (Briso et al. 2014a, b). Thus, in most cases, the microabrasive treatment is complemented with bleaching because of the more yellowish color that the teeth present after wear of the enamel.

Therefore, the bleaching treatment is carried out prior to microabrasion, which may be sufficient to make the intrinsic enamel stains partially or totally imperceptible as previously described. If the enamel microabrasion is still necessary, teeth may have a more yellowish appearance due to the enamel removal and consequent approach to the dentin tissue. In these cases, an interval of 7 days is recommended before at-home bleaching can be initiated with low-concentration peroxide products.

4.3.3 Change in Hardness/Susceptibility to Caries/ Demineralization/Importance of Saliva

The effect of bleaching agents on dental enamel has been extensively investigated in the literature (Kwon et al. 2002; Spalding et al. 2003; Cavalli et al. 2004; Faraoni-Romano et al. 2008; Forner et al. 2009). Morphological changes, increased surface porosity, exposure of prisms, reduced organic content, change in the calcium/phosphate proportion, and reduced microhardness are the main changes that occur in the bleached enamel. These changes depend on the contact time of the gel with the dental substrate, the H_2O_2 concentration in the product, and the pH of the product during its use.

In the at-home bleaching technique, the changes in enamel structure have been shown to be related to the long contact time of the product with the tooth surface. Studies have shown that a single 10% CP application for 3 or 8 h does not result in a significant change in enamel surface micromorphology. However, when the product is applied for 14 consecutive days, superficial erosion areas could be observed. On the other hand, when this product was applied for only 1 h daily, changes in the mineral content of the enamel were not observed even after 21 days of treatment (Dudea et al. 2009; Sasaki et al. 2009). Thus, reducing the contact time or the period of application of home bleaching gels can prevent damage to tooth structure. The CP concentration in the bleaching gel also influences this process. Soares et al. (2013a, b) showed that a gel with 16% CP promoted the formation of deeper pores on the enamel surface with respect to the gel with 10% CP, this change being related to the more pronounced loss of calcium and phosphorus. According to the authors, as all the other parameters have been standardized (pH of the bleaching gel, contact time, the interval between applications, and the total treatment time), the H_2O_2

concentration in the bleaching gel was responsible for the most intense changes observed when a gel with 16% CP was used.

As the pH of home gels ranges from 5.6 to 7.3 and the urea released during the degradation of CP increases the pH within 15 min, the pH of home gels is unlikely to have any association with structural changes in the enamel, even with prolonged contact time with the tooth surface. Thus, the pores are considered to have been formed on the enamel surface after bleaching, because of the disruption of enamel protein matrix and subsequent loss of the crystalline material surrounded by this matrix. This hypothesis derives from the observation in several studies that enamel dissolution occurs heterogeneously, with areas of erosion interleaved with areas of intact enamel (Kwon et al. 2002; Spalding et al. 2003; Cavalli et al. 2004). According to the authors, as the distributions of proteins and other organic materials are uneven on the enamel surface, the defects observed after bleaching occur heterogeneously (Kwon et al. 2002). Other studies demonstrated that the dissolution occurs primarily in the interprismatic regions and in the enamel hypomineralization areas, which are the regions with the greatest amount of organic material (Spalding et al. 2003; Cavalli et al. 2004).

When gels with high H_2O_2 concentrations were used in the in-office technique, the morphological changes on the enamel surface were observed even after a single application of the product on the enamel, where the surface was rougher and the pores were deeper than those observed after home bleaching (Kwon et al. 2002; Spalding et al. 2003; Cavalli et al. 2004). For these gels, it is believed that a joint action occurs between the oxidative effect of H_2O_2 and acid pH. Although the average pH of in-office bleaching products is around 6.5, many gels have a pH between 3.6 and 5.0 (Price et al. 2000), which are values below the critical pH for enamel dissolution (5.5). Recent studies have shown that the pH of the bleaching product has a direct relationship with the roughness of tooth enamel after bleaching and that the pH of bleaching agents tends to decrease according to the contact time with the tooth structure (Trentino et al. 2015; Abe et al. 2016).

Despite the various morphological changes observed on the enamel surface, studies showed that these changes can be considered mild to moderate. However, the contact of bleaching products with the dentine can cause more severe changes. Wear resistance reduction (Faraoni-Romano et al. 2009), decreased hardness (Faraoni-Romano et al. 2008; Forner et al. 2009), and increased surface roughness (Faraoni-Romano et al. 2008) have been demonstrated to be more pronounced on the enamel. These findings can be explained by the dentinal tissue composition, which has a greater organic content and presents an increased susceptibility to the oxidative action of H_2O_2 and acid pH of the bleaching gels, as the critical pH value for the dentinal dissolution is between 6.2 and 6.7 (Faraoni-Romano et al. 2009). Therefore, the contact of bleaching agents with exposed dentin areas is highly contraindicated.

As the changes in the enamel are considered subtle, how to extrapolate these results to the in vivo situation remains a challenge, where factors such as saliva and the presence of fluorides may act to remineralize tooth structure (Kwon et al. 2002). Studies that performed bleaching in situ (Rodrigues et al. 2005; Faraoni-Romano

et al. 2009) or applied human or artificial saliva to specimens in between the bleaching procedure (Spalding et al. 2003; Faraoni-Romano et al. 2008; Sasaki et al. 2009) showed insignificant changes in the enamel, which is attributable to the remineralizing action of saliva. Sasaki et al. (2009) also demonstrated that the storage in artificial saliva of specimens bleached for 14 days resulted in a significant increase in microhardness. In their study, Spalding et al. (2003) observed on scanning electron microscopy that bleaching with H_2O_2 at 35% followed by immersion in human saliva for 1 week resulted in the formation of a granular blanket on the enamel surface, which was probably due to remineralization process by saliva. Soares et al. (2013a, b) observed that the use of solutions with 0.2% and 0.05% sodium fluoride for 1 min after each application of the bleaching gel prevented the structural changes observed in the enamel when gels containing 10% and 16% CP were used. Kemaloğlu et al. (2014) also demonstrated that fluorinated solutions (2.1% sodium fluoride) could significantly prevent mineral loss in the enamel subjected to bleaching with gels containing 38% H_2O_2.

Although these changes tend to reverse when in contact with saliva and fluoride, the use of peroxides in demineralized areas may enhance existing changes. In this context, during clinical examination, the practitioner must pay attention to the presence of incipient carious lesions that may have had its evolution favored due to the bleaching treatment. In a recent study conducted by our group, we found that the application of a gel with 35% H_2O_2 (three times for 15 min) on specimens with demineralized enamel to simulate incipient lesion caries resulted in a more intense H_2O_2 diffusion over the tooth structure than that observed in healthy and bleached specimens. In the same study, we verified a greater reducing effect on enamel microhardness when demineralized specimens were bleached, wherein the bleaching increased the depth of demineralization of incipient caries lesions. The surface and subsurface morphologies were also more heavily affected in the previously demineralized enamel subjected to bleaching (Briso et al. 2015a, b).

Thus, at the end of the bleaching treatment, the presence of saliva and use of fluorides to promote mineral saturation in the tooth structure are important to promote a reduction in the demineralization process and an increase in the remineralization of tooth structures. Prior to tooth bleaching, the practitioner should perform a careful analysis in order to detect the presence of exposed dentin areas, enamel hypomineralization, and incipient carious lesions, considering that application of bleaching gel is contraindicated in these regions.

4.4 Effects on Restorations

Patients who seek to undergo bleaching treatment may have various types of restorations. Successful tooth bleaching is achieved by the direct contact of the bleaching gel with the teeth and, hence, with the restorations, which may affect the characteristics of the restorative material (Polydorou et al. 2007a, b). The main changes are related to the surface roughness (Türker and Biskin 2002, 2003), microhardness

(Türker and Biskin 2002), changes in color (Gurbuz et al. 2013), and the marginal integrity of the restorations (Ulukapi et al. 2003).

4.4.1 Roughness

Surface roughness is an important feature of restorative materials. Good polishing of restorations provides lower risk of plaque retention and esthetic excellence, which ultimately increase the longevity of restorations (Steinberg et al. 1999). In the literature, the effect of bleaching agents on the roughness of restorative materials is controversial. Light changes in the surface roughness of resin hybrid materials after in-office bleaching (Hayacibara et al. 2004) and formation of microscopic cracks on the surface of the composite (Mourouzis et al. 2013) have been reported, as well as inert effects on amalgam restorations, composite resin, glass ionomer, and porcelain exposed to bleaching products (de A Silva et al. 2006).

In any case, new polishing should be considered in restorations subjected to bleaching treatment, as no matter how mild, roughening of the restorative materials might occur. Research studies that use the same bleaching products and methodologies are rare, making a direct comparison of results impossible. In actual clinical practice, restorations are simultaneously subjected to the formation of biofilm, tooth brushing, and mastication, besides the chemical challenges in the oral cavity, conditions that are hardly simulated in laboratory studies. Meanwhile, saliva could dilute the bleaching gel, often reducing its concentration and its effect on the surface of the restorative materials (Wattanapayungkul et al. 1999; Steinberg et al. 1999; Silva et al. 2006).

We emphasize that the roughness of indirect restorative materials such as fiber reinforced composites and porcelain is increased after exposure to bleaching agents. The Bis-GMA and UDMA matrix of indirect resins is greatly affected by the action of bleaching products, causing the erosion of the resin matrix and the consequent displacement of filler particles. In turn, porcelains may also exhibit changes in surface roughness (Türker and Biskin 2003; Schemehorn et al. 2004; Torabi et al. 2014a, b) that are attributed to the reduction in SiO_2 and K_2O_2 molecules (Moraes et al. 2006). These findings, however, are opposed to those of a previous study that polished porcelains had a higher resistance to bleaching products (Butler et al. 2004). These controversial results reported in the literature can be explained by the different methodologies and bleaching products used. While some studies use actual dosages, others subject their specimens to long periods of exposure to the bleaching product.

4.4.2 Hardness

The hardness of a material essentially relates to its properties, which in turn interferes with its durability (Atash and Van den Abbeele 2005; AlQahtani 2013). Reports showed reduced Vickers and Knoop hardness of resin materials when

exposed to bleaching agents. Reactive oxygen species are believed to promote the cleavage of polymer chains, degrading the organic matrix that leads to the chemical softening of resin (Taher 2005; de Alexandre et al. 2006; Polydorou et al. 2007a, b; Briso et al. 2010a, b; AlQahtani 2013). For the same reason, the hardness of the pit-and-fissure sealants subjected to bleaching with low concentrations of CP was reduced. In this case, the materials that showed the lowest microhardness values were those without filler particles because of their larger organic matrix (de Alexandre et al. 2006).

An in vitro study (Torabi et al. 2014a, b) also demonstrated changes in porcelain microhardness. Although these values were significant, the release of SiO_2 was not clinically observed. An important factor to be emphasized is that glazed surfaces seemed less susceptible to hardness changes while the opposite was observed in polished pieces (Torabi et al. 2014a, b). Thus, the preparation of the parts can be greatly useful before the beginning of the bleaching treatment.

It is noteworthy that the bleaching products are highly unstable and that their pH can affect the Knoop hardness of the restorative materials. For this reason, some bleaching agents may cause more changes than others may. Therefore, the selection of bleaching agents that keep the pH around 7 throughout the complete bleaching procedure is recommended (Briso et al. 2010a, b).

4.4.3 Change in Color, Brightness, and Fluorescence

These properties have great importance to the esthetic restorations of composite resin and porcelain. The color, brightness, and fluorescence of direct and indirect restorative materials are known to be changed during the bleaching treatment (Canay and Cehreli 2003; Hubbezoglu et al. 2008; Li et al. 2009; Kara et al. 2013). However, the color change that occurs in the dental tissue is much more intense, making it imperative to replace the esthetic restorations after the bleaching treatment. Therefore, it is recommended to wait until the dental tissue is rehydrated and reaches color stability, which occurs approximately 15 days after completion of the bleaching treatment. This period coincides with the time required to eliminate the oxygen stored in the tooth structure, restoring the effectiveness of adhesive intermediate agents.

Significant changes in brightness and fluorescence of restorative materials were also found after bleaching, reinforcing the need to replace esthetic restorations as part of treatment plans (Yalcin and Gurgan 2005; Gurbuz et al. 2013; Klukowska et al. 2013; Bueno et al. 2013). In porcelains subjected to low-concentration bleaches, these changes were observed and attributed to the type and structure of the crystals present in the porcelain studied. Hybrid porcelains, with great organic content, are more susceptible to color changes during bleaching, showing less color stability in chemical challenges (Kara et al. 2013). We must, however, take into account that none of these studies were conducted in a situation identical to the oral environment, where the presence of saliva could change the results.

4.4.4 Marginal Micro Infiltration and Effects on Bond Strength

Currently, restorative techniques are based on the adhesive bonding of resin materials to tooth structure. Some studies showed changes in the marginal sealing of restorations subjected to bleaching treatment (Owens et al. 1998), causing a decrease in the bond strength of the same (Cavalli et al. 2005).

Moreover, class V restorations subjected to bleaching treatment have been reported to present the greatest changes in the adhesive system interface with the dentin tissue, making these regions more prone to the occurrence of micro infiltration (Bektas et al. 2013). The difference between the substrates suggests that the deleterious action of peroxides is more pronounced in tissues with higher organic content (Carrasco-Guerisoli et al. 2009). This fact was also confirmed by White et al. (2008), who showed that the occurrence of marginal microleakage of class I restorations was not influenced by treatment with different bleaching products.

Considering the findings reported in the recent literature, a thorough evaluation of preexisting restorations must be carried out. In case of deficient adjustment of the restoration margins, a pit-and-fissure sealant or a dental adhesive may be used to seal the tooth-restoration interface.

As mentioned previously, the restorations with esthetic involvement need to be replaced after bleaching. In such cases, residual oxygen from the decomposition of bleaching agents may be present within the dental tissues. This oxygen interferes negatively with dental adhesion as well as with the degree of conversion of resin-based restorative materials (Cavalli et al. 2005; Briso et al. 2014a, b). This requires an interval of 7 to 14 days between the end of the bleaching treatment and the replacement of the restorations to eliminate all the excess oxygen (Briso et al. 2014a, b).

Previous studies suggested the use of antioxidants to reduce this interval between the end of the bleaching treatment and the adhesive restorative procedures aiming to counteract the negative effects of the presence of residual oxygen (Freire et al. 2009; Garcia et al. 2012; Briso et al. 2014a, b; Arumugam et al. 2014). Although many antioxidants have been studied, such as lycopene, proanthocyanidins, and α-tocopherol (Arumugam et al. 2014), 10% sodium ascorbate is the most widely studied (Briso et al. 2014a, b). Its application is recommended for 5–10 min prior to performing the restorative procedures (Freire et al. 2009; Briso et al. 2012, 2014a, b). The use of sodium ascorbate has been associated with a significant improvement in the marginal sealing of the restorations, increased bond strengths, and preservation of micromechanical interactions that occur between the adhesive system and the tooth substrate (Abraham et al. 2013).

Some caution, however, should be taken when performing restorations immediately after the bleaching treatment. The reason is that the teeth may appear dehydrated with an unstable color. Usually there is a color rebound within a few days.

4.5 Tooth Sensitivity

4.5.1 Symptoms

Reactive oxygen species from bleaching products quickly reach the pulp-dentin complex, triggering a series of biological reactions that may change the pulp condition which triggers pain. Tooth sensitivity is the most frequent clinically detectable side effect of the bleaching treatment, and its occurrence raises concerns for practitioners and causes discomfort to patients, leading to discontinuation of the treatment.

The penetration of H_2O_2 into the dental pulp results in the release of biochemical mediators involved in the inflammatory process. These mediators sensitize the pulp nociceptors and play a role in pain modulation by causing an increase in vascular permeability and vasodilation, changing the sensitivity threshold of nerve fibers (Markowitz 2010). Moreover, when the peroxide from bleaching agents comes in contact with MDPC-23 odontoblast cells, significant changes in their morphology may occur with a decrease in the mitochondrial respiration rate (Costa et al. 2010; Soares et al. 2014a, b). Despite the obvious differences between the experimental models, tests conducted in guinea pigs also confirm the aggressive potential of the bleaching treatment. Such damages were proportional to the number of in-office bleaching sessions with 35% H_2O_2 (Cintra et al. 2013). In turn, studies on human teeth show that excessive exposure to peroxides can lead to a slight disturbance in the odontoblast layer on premolars and coagulation necrosis areas in lower incisors subjected to in-office bleaching treatment (Costa et al. 2010; Kina et al. 2010).

Several research projects have been carried out with the goal of minimizing these undesired effects (Giniger et al. 2005; Armênio et al. 2008; Tay et al. 2009). Neurosensory investigations through quantitative tests have led to the conclusion that patients who undergo bleaching treatments experience different levels of discomfort, a fact observed when the painful tooth sensitivity threshold was altered (Rahal et al. 2014).

In clinical practice, the methods used to minimize patient discomfort rely on the administration of analgesics and/or the use of topical desensitizing agents, which are added to the composition of some bleaching agents (Jorgensen and Carroll 2002; Croll 2003; Giniger et al. 2005; Haywood 2005; Armênio et al. 2008; Tay et al. 2009; Basting et al. 2012). Several types of desensitizing agents with different action mechanisms have been used, some having physical action that obliterates the dentinal tubules while others having neural action that blocks nerve stimulation (Tay et al. 2009; Basting et al. 2012; Palé et al. 2014).

Indeed, some desensitizers are effective and reduce the discomfort caused by the bleaching treatment. A recent report (Rahal et al. 2014) showed a reduction in the neurosensorial response of teeth treated with a desensitizer after bleaching. In this split-mouth design study, the bleaching treatment was performed on the maxillary arch. One hemiarch received a topical desensitizer containing 5% potassium nitrate and 2% sodium fluoride, while the other arch served as negative control. The results obtained after the use of the desensitizer showed a clear reduction in sensitivity.

Despite all these studies, products or techniques that restrict the action of peroxides on dental pigments or that effectively modulate their penetration in the pulp tissue have not been developed yet. There is a need to consider tooth bleaching as a therapy in which a H_2O_2 peroxide-based agent is topically applied to tooth enamel, causing undesirable side effects. Therefore, specific treatments are needed for delivering controlled peroxide dosages according to individual patient conditions.

Young patients with a wide pulp chamber should be treated very conservatively with low-concentration products and with intermittent use by restricting the total number of hours per day.

In general, special attention should be given to the dosage used in our patients. Sometimes, the practitioner may intuitively think that the greater the amount of peroxide that penetrates into dentin, the greater the color changes obtained. However, at-home and in-office bleaching therapies provide similar results, taking an average of 3 weeks for achieving desirable results (Bernardon et al. 2010). In the case of the in-office technique, the 30-min application time has been proven to provide the same results as the 45-min exposure to the bleaching agent. The continuous renewal of the bleaching product every 15 min has proven unnecessary to achieve bleaching results, as the product retains its activity throughout the clinical session (Marson et al. 2015). In fact, the regimen most often adopted (from 45 to 60 min with multiple exchanges of the product) substantially increases peroxide penetration into the pulp tissue (Costa et al. 2010; Soares et al. 2014a, b).

Another factor to be considered is the condition of the oral environment. Besides recommending the bleaching techniques, the dental professional must be aware of the alternative routes of peroxide diffusion. If neglected, they may increase the penetration of peroxide into the pulp chamber.

In this context, despite being considered a dose-dependent therapy based on the topical application of a peroxide agent to the dental structure, bleaching products are still available without basic information related to the respective safety and effective dosages. The instructions that come with the beaching product do not include relevant information such as the amount of bleaching product required to obtain a satisfactory result without causing pulp damage. Therefore, dental professionals do not have access to important information about the safe volume of gel to be applied to the teeth. Clinicians must rely on their common sense and clinical experience (Rahal et al. 2018; Al-Omiri et al. 2018).

However, it is necessary to underline that the ROS originating in the whitening gel must generate a chemical imbalance in the region for tooth whitening to occur. To reestablish the normal conditions, the ROS change to a lower concentration inside the tooth structure. Thus, a greater availability of ROS into the tooth structure as a result of excessive volume of gel would intensify this imbalance, favoring greater penetration into the dental structure (Cintra et al. 2016; Kurzmann et al. 2019). However, studies have recently shown that the relationship between the volume of the gel and whitening effect is not linear; that is, the chromatic change does not increase proportionally to an increase in the amount of gel applied to the tooth (Esteves et al. 2022b).

The clinical cases presented in Figs. 4.12, 4.13, and 4.14 show that changing the volume of the bleaching product does not produce any benefit in chromatic change while increasing the occurrence of post-bleaching sensitivity. The gel was collected with special pipette tips for viscous liquids by applying the specific amount of gel in each experimental case. The gel remained in contact with the area of interest for 45 min in three bleaching sessions. The patients underwent in-office bleaching treatment with a 35% H_2O_2-based bleaching gel without the use of any source of physical activation.

The determination of a value to be considered as a control was made using the limited information provided by the manufacturer, which indicated that a 5-gr vial of bleaching gel would be sufficient for four whitening sessions in 20 teeth. Thus, we set 0.06 gr (0.05 mL) of gel per tooth as a control. The effect of applying half and twice the volume (0.025 mL and 0.10 mL, respectively) on chromatic change and post-bleaching sensitivity was also evaluated.

In Fig. 4.12, incisors and canines had a baseline shade of A2. 0.025 mL of bleaching gel (35% H_2O_2) was applied to the right hemiarch, while 0.05 mL of gel was applied to the left hemiarch (control treatment).

Figure 4.13 shows the patient in Case 2 with shade A3 in the VITA shade guide. This patient received 0.025 mL of whitening gel in the right hemiarch, while in the left hemiarch the gel was applied in the amount of 0.10 mL.

In Fig. 4.14, the left hemiarch received a volume of 0.10 mL of gel, while the right hemiarch was treated with 0.05 mL of gel.

The data were measured on a portable spectrophotometer and analyzed according to Paravina et al. (2019). When exploring the results obtained in the cervical region, the clinical cases depicted in Figs. 4.12 and 4.13 showed a perceptible but acceptable difference in this region after the first bleaching session. However, after the second session and at all other times, there were no perceptible differences among all clinical cases. Comparing the chromatic change in the incisal area, all

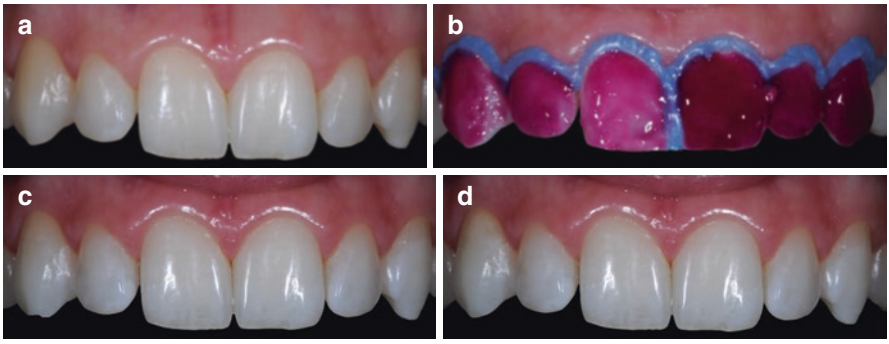

Fig. 4.12 Treatment performed with application of 35% H_2O_2 bleaching gel in a volume of 0.025 mL vs. 0.05 mL. (**a**) Initial appearance of maxillary incisors and canines with shade VITA A2. (**b**) Application of the bleaching gel. (**c**) Clinical aspect after the first session. (**d**) Clinical aspect after the third session. Homogeneous chromatic changes are observed at the end of the bleaching treatment regardless of the volume of gel used

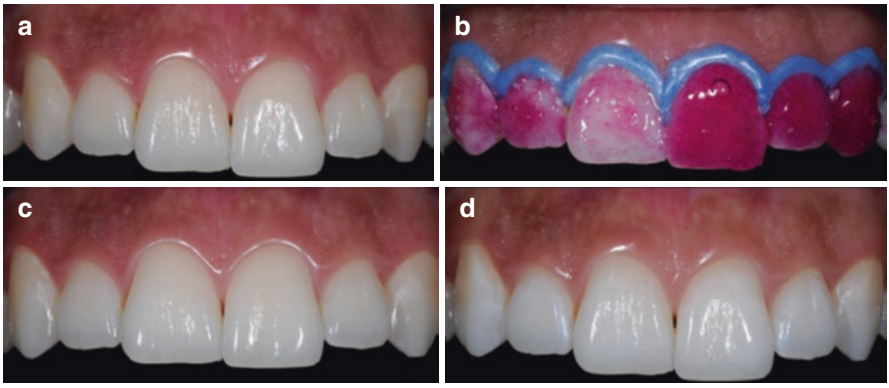

Fig. 4.13 Treatment performed with application of 35% H_2O_2 bleaching gel in a volume of 0.025 mL vs. 0.10 mL. (**a**) Initial appearance of maxillary incisors and canines with shade VITA A3. (**b**) Application of the bleaching gel. (**c**) Clinical aspect after the first session. (**d**) Clinical aspect after the third session. Homogeneous chromatic changes are observed at the end of the bleaching treatment regardless of the volume of gel used

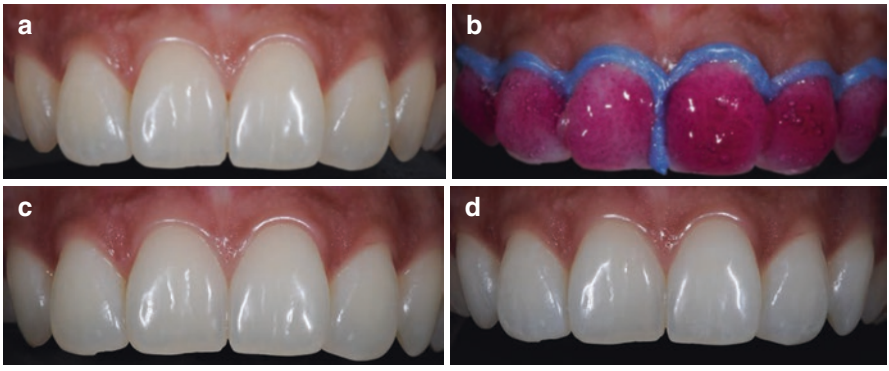

Fig. 4.14 Treatment performed with application of 35% H_2O_2 bleaching gel in a volume of 0.050 mL vs. 0.10 mL. (**a**) Initial appearance of maxillary incisors and canines with shade VITA A2. (**b**) Application of the bleaching gel. (**c**) Clinical aspect after the first session. (**d**) Clinical aspect after the third session. Homogeneous chromatic changes are observed at the end of the bleaching treatment regardless of the volume of gel used

patients remained below the limits of perceptibility. These data can be seen in Fig. 4.15.

These clinical findings mean that there was a correlation between the amount of gel deposited and tooth sensitivity in function of time. Tooth sensitivity resulting from bleaching treatment is not yet fully understood, but the excessive presence of ROS from bleaching products in the pulp tissue seems to stimulate the release of inflammatory chemical mediators, such as substance P, which sensitizes pulp nociceptors, acting in the modulation of pain in reports of spontaneous sensitivity (Briso et al. 2018; Esteves et al. 2022b).

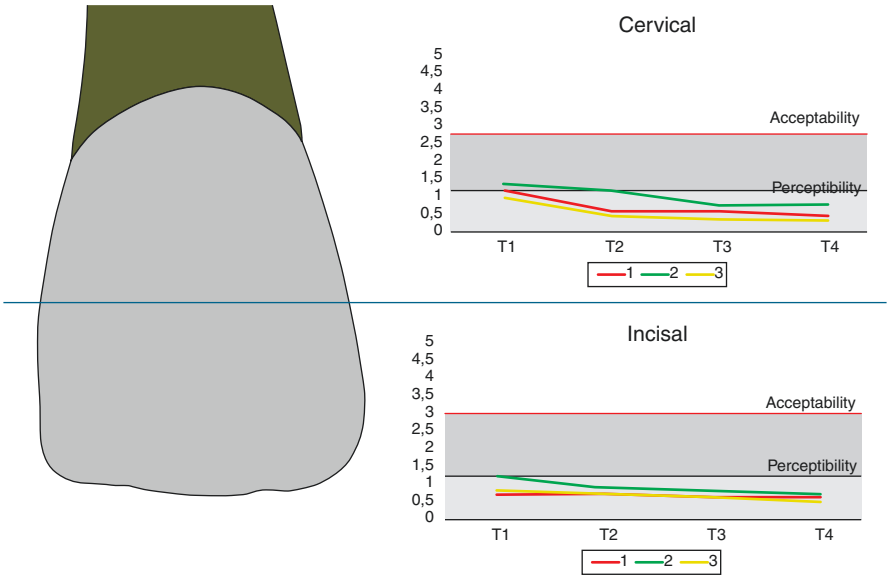

Fig. 4.15 Comparison of the perceptibility and acceptability limits with the ΔE values obtained in the cervical and incisal region between the hemiarches (red line, application of 0.025 mL of gel vs. application of 0.05 mL (Fig. 4.12); green line, application of 0.025 ml vs. application of 0.10 ml (Fig. 4.13); yellow line, application of 0.05 ml vs. application of 0.10 ml (in function of time) (Fig. 4.14))

As the excess gel did not increase the bleaching effect, the unreacted peroxide, known as free H_2O_2, may interact with the pulp cells, resulting in injuries of different magnitude, a topic that will be explored in-depth in Chap. 5.

Although several studies have evaluated the effects of coadjuvant therapies on tooth sensitivity, such as antioxidants and even anti-inflammatory drugs (Vargas et al. 2014; May et al. 2010), it seems that controlling the volume of the bleaching gel can also help prevent tooth sensitivity without interfering with the esthetic results. Thus, the bleaching effect obtained with the in-office bleaching treatment did not show a direct correlation with the volume of bleaching gel applied to the enamel. However, the adverse effects related to the penetration of ROS into the pulp tissue were volume-dependent.

4.5.2 Protection Protocols

The treatment options currently adopted by clinicians may result in undesirable biological effects, particularly when the oral cavity is not evaluated prior to receiving H_2O_2-based products and when the dosage is not adjusted for each patient. In addition to making sure that we evaluate the adequate dosage for each patient, we

may be able to manage specific conditions in which the penetration of peroxide into the pulp tissue is increased causing undesirable side effects to patients.

4.5.3 Incipient Carious Lesions

Owing to the difficulty of diagnosis or lack of information, incipient carious lesions often do not receive adequate attention prior to tooth bleaching. Several studies have shown that bleaching provides transitional histological changes in the enamel (Akal et al. 2001; Bistey et al. 2007; Severcan et al. 2008). However, performing a bleaching treatment on a substrate with incipient carious lesions may accelerate the evolution of the lesion to reach deeper areas of dental enamel faster (De Arruda et al. 2012; Briso et al. 2015a, b).

The presence of demineralized areas has also been recently associated to the amount of peroxide that reaches the dentin-pulp complex. Demineralized substrate has been found to offer lower resistance to the penetration of H_2O_2 (Briso et al. 2015a, b), resulting in greater posttreatment sensitivity. Thus, bleaching is contraindicated for teeth with demineralized areas.

Once white spot lesions are detected and their specific characteristics identified, the dental professional must establish the most appropriate therapeutic approach for each case (Hicks et al. 1984; Hunt 1990; Willmot 2004). This approach begins with the identification of the causative factor of the imbalance and the use of daily low-concentration fluoride rinses or mouthwashes (0.05%). Depending on the case, the practitioner can increase the dose exposure to fluorides with weekly application of 5% fluoride varnish or the application of 1.23% acidulated fluoride-phosphate gel (Pinto 2001) a few weeks before the bleaching treatment until the remineralization of the region is observed.

The application time of the fluoride treatment varies according to the product used. Fluoride rinses are kept on the tooth surface for 4 min according to the American Dental Association Council on Scientific Affairs (Braxton et al. 2014; Pinto 2001), while the fluoride varnish is maintained on the treated surface for 24 h. The bleaching treatment can be performed after enamel remineralization is detected. In cases where the white spot areas show signs of activity during the bleaching treatment, discontinuation of treatment and remineralization of new lesions are recommended.

4.5.4 Presence of Cracks in the Enamel

The presence of cracks in the enamel is not uncommon on buccal surfaces, though rarely valued by clinicians. These fissures within the enamel extend usually in the cervical-incisal/occlusal direction, even reaching the dentin-enamel junction and causing fractures of the tooth structure (Abbott and Leow 2009).

These defects on the enamel surface allow the penetration of peroxides used in the bleaching treatment (Briso et al. 2014a, b) and may be harmful to the pulp, increase perioperative and postoperative sensitivity and even cause pain. Thus, regardless of the bleaching technique used, sealing these cracks with adhesive materials is recommended.

4.5.5 Exposed Dentin Areas

Exposed dentin areas, especially in the cervical and incisal regions, are common in the oral cavity. Exposed dentin facilitates the diffusion of peroxide causing sensitivity during the course of treatment. For this reason, it is essential to protect these areas with appropriate resin-based materials.

The presence of cavitation determines the type of treatment in the cervical region. In case of caries lesions around the cervical area, restoration with resin-modified glass ionomer (RMGIC) is recommended, with the possibility of veneering the RMGIC with composite resin after the bleaching treatment.

When the cervical dentin is exposed without cavitation, the insertion of a restorative material will result in an anatomical overcontour in the region. For this reason, we suggest the application of an adhesive system to seal the dentinal tubules in the region. The material of choice and technique recommended for these cases is a dental adhesive in self-etch mode scrubbed on the dentin surface and light-cured (Yousaf et al. 2014). However, because of the solubility of adhesives in the oral environment, the sensitivity may relapse in case of longer bleaching treatments. Therefore, reapplications of the adhesive are often necessary (Baracco et al. 2012). Similarly, exposed dentin on the incisal surface of mandibular incisors and canines is common. These regions must also be protected prior to the bleaching treatment, although in this case, a pit-and-fissure sealant may be used as there is enamel surrounding the area (Fig. 4.16).

4.5.6 Presence of Restorations with Marginal Discrepancies

The restorations on teeth that will undergo bleaching treatment must be evaluated for the presence of fractures and marginal discrepancies, which may serve as a pathway for easy diffusion of peroxides. These areas of the restorations must be protected by sealing the tooth-restoration interface to better control the penetration of the bleaching material into the tooth structure (Patri et al. 2013).

Although no material has the ability to hermetically seal the tooth-restoration interface (Gokay et al. 2000; De Munck et al. 2005; Cenci et al. 2008), the movement of dentinal fluid toward the tooth surface (Vongsavan and Matthews 1991), associated with the use of sealing materials, is believed to serve as a protective measure against the deleterious effects of peroxides. Dentin adhesive systems and pit-and-fissure sealants, which penetrate easily into the crevices and marginal

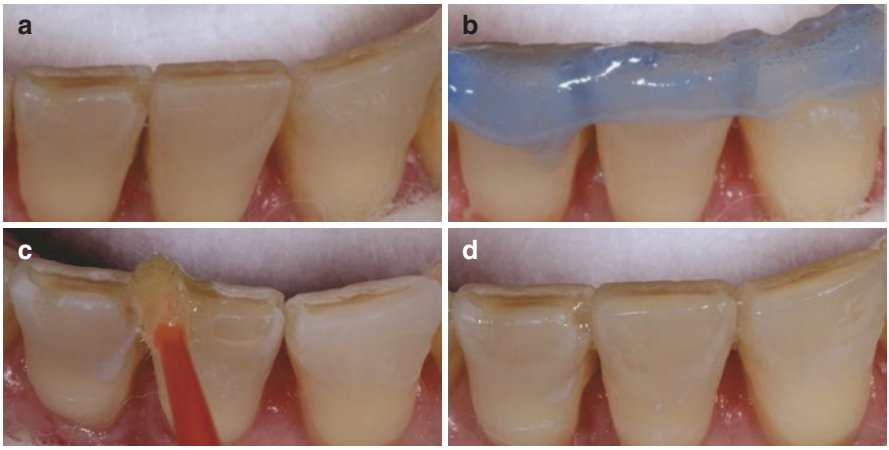

Fig. 4.16 (**a**) Incisal region with exposure of dentin tissue. (**b**) Conditioning using the total-etch technique. (**c**) Application of the adhesive material. (**d**) Teeth are ready to start the bleaching procedure

defects, are materials of choice for marginal sealing of the restorations, forming an effective physical barrier during the course of the bleaching treatment.

References

Abbott P, Leow N (2009) Predictable management of cracked teeth with reversible pulpitis. Aust Dent J 54:306–315

Abe AT, Youssef MN, Turbino ML (2016) Effect of bleaching agents on the nanohardness of tooth enamel, composite resin, and the tooth-restoration Interface. Oper Dent 41:44–52

Abraham S, Ghonmode WN, Saujanya KP, Jaju N, Tambe VH, Yawalikar PP (2013) Effect of grape seed extracts on bond strength of bleached enamel using fifth and seventh generation bonding agents. J Int Oral Health 5:101–107

Akal N, Over H, Olmez A, Bodur H (2001) Effects of carbamide peroxide containing bleaching agents on the morphology and subsurface hardness of enamel. J Clin Pediatr Dent 25: 293–296

Albuquerque CR, Gomez RS, Dutra RA, Vasconcellos WA, Gomez RS, Gomez MV (2002) Effects of a 10% carbamide peroxide bleaching agent on rat oral epithelium proliferation. Braz Dent J 13:162–165

Almeida LC, Riehl H, Santos PH, Sundfeld ML, Briso AL (2012) Clinical evaluation of the effectiveness of different bleaching therapies in vital teeth. Int J Periodontics Restorative Dent 32:303–309

Almeida AF, Torre Edo N, Selayaran Mdos S, Leite FR, Demarco FF, Loguercio AD, Etges A (2015) Genotoxic potential of 10% and 16% carbamide peroxide in dental bleaching. Braz Oral Res 29:S1806–S83242015000100217

Al-Omiri MK, Al Nazeh AA, Kielbassa AM, Lynch E (2018) Randomized controlled clinical trial on bleaching sensitivity and whitening efficacy of hydrogen peroxide versus combinations of hydrogen peroxide and ozone. Sci Rep 8:2407

AlQahtani MQ (2013) The effect of a 10% carbamide peroxide bleaching agent on the microhardness of four types of direct resin-based restorative materials. Oper Dent 38:316–323

Armênio RV, Fitarelli F, Armênio MF, Demarco FF, Reis A, Loguercio AD (2008) The effect of fluoride gel use on bleaching sensitivity: a double-blind randomized controlled clinical trial. J Am Dent Assoc 139:592–597

Arumugam MT, Nesamani R, Kittappa K, Sanjeev K, Sekar M (2014) Effect of various antioxidants on the shear bond strength of composite resin to bleached enamel: an in vitro study. J Conserv Dent 17:22–26

Atash R, Van den Abbeele A (2005) Bond strengths of eight contemporary adhesives to enamel and to dentine: an in vitro study on bovine primary teeth. Int J Paediatr Dent 15:264–273

Auschill TM, Schneider-Del Savio T, Hellwig E, Arweiler NB (2012) Randomized clinical trial of the efficacy, tolerability, and long-term color stability of two bleaching techniques: 18-month follow-up. Quintessence Int 43:683–694

Baracco B, Fuentes MV, Garrido MA, Gonzalez-Lopez S, Ceballos L (2012) Effect of thermal aging on the tensile bond strength at reduced areas of seven current adhesives. Odontology 101:177–185

Basting RT, Amaral FL, França FM, Flório FM (2012) Clinical comparative study of the effectiveness of and tooth sensitivity to 10% and 20% carbamide peroxide home-use and 35% and 38% hydrogen peroxide in-office bleaching materials containing desensitizing agents. Oper Dent 37:464–473

Bektas ÖÖ, Eren D, Akin GG, Sag BU, Özcan M (2013) Microleakage effect on class V composite restorations with two adhesive systems using different bleaching methods. Acta Odontol Scand 71:1000–1007

Bernardon JK, Sartori N, Ballarin A, Perdigão J, Lopes GC, Baratieri LN (2010) Clinical performance of vital bleaching techniques. Oper Dent 35:3–10

Bistey T, Nagy IP, Simó A, Hegedus C (2007) In vitro FT-IR study of the effects of hydrogen peroxide on superficial tooth enamel. J Dent 35:325–330

Boushell LW, Ritter AV, Garland GE, Tiwana KK, Smith LR, Broome A, Leonard RH (2012) Nightguard vital bleaching: side effects and patient satisfaction 10 to 17 years post-treatment. J Esthet Restor Dent 24:211–219

Braxton A, Garrett L, Versluis-Tantbirojn D, Versluis A (2014) Does fluoride gel/foam application time affect enamel demineralization? J Tenn Dent Assoc 94:28–31; quiz 32–33

Briso AL, Tuñas IT, de Almeida LC, Rahal V, Ambrosano GM (2010a) Effects of five carbamide peroxide bleaching gels on composite resin microhardness. Acta Odontol Latinoam 23: 27–31

Briso ALF, Fonseca MSM, Almeida LCAG, Mauro SJ, Santos PH (2010b) Color alteration in teeth subjected to different bleaching techniques. Laser Phys 20:2066–2069

Briso AL, Toseto RM, Rahal V, dos Santos PH, Ambrosano GM (2012) Effect of sodium ascorbate on tag formation in bleached enamel. J Adhes Dent 14:19–23

Briso AL, Lima AP, Gonçalves RS, Gallinari MO, dos Santos PH (2014a) Transenamel and transdentinal penetration of hydrogen peroxide applied to cracked or microabrasioned enamel. Oper Dent 39:166–173

Briso AL, Rahal V, Sundfeld RH, dos Santos PH (2014b) Alexandre RS (2014) effect of sodium ascorbate on dentin bonding after two bleaching techniques. Oper Dent 39:195–203

Briso AL, Gonçalves RS, Costa FB, Gallinari Mde O, Cintra LT, Santos PH (2015a) Demineralization and hydrogen peroxide penetration in teeth with incipient lesions. Braz Dent J 26:135–140

Briso ALF, Gonçalves RS, da Costa FB, Gallinari MO, Cintra LTA, dos Santos PH (2015b) Demineralization and hydrogen peroxide penetration in teeth with incipient lesions. Braz Dent J 26:135–140

Briso ALF, Rahal V, Azevedo FA, Gallinari MO, Gonçalves SR, Frascino SMB, Santos PH, Cintra LTA (2018) Neurosensory analysis of tooth sensitivity during at home dental bleaching: a randomized clinical trial. J Appl Oral Sci 26:e20170284

Buchalla W, Attin T (2007) External bleaching therapy with activation by heat, light or laser--a systematic review. Dent Mater 23:586–596

Bueno RP, Salomone P, Villetti MA, Pozzobon RT (2013) Effect of bleaching agents on the fluorescence of composite resins. Eur J Esthet Dent 8:582–591

Butler CJ, Masri R, Driscoll CF, Thompson GA, Runyan DA, Anthony von Fraunhofer J (2004) Effect of fluoride and 10% carbamide peroxide on the surface roughness of low-fusing and ultra lowfusing porcelain. J Prosthet Dent 92:179–183

Canay S, Cehreli MC (2003) The effect of current bleaching agents on the color of light-polymerized composites in vitro. J Prosthet Dent 89:474–478

Carrasco-Guerisoli LD, Schiavoni RJ, Barroso JM, Guerisoli DM, Pécora JD, Fröner IC (2009) Effect of different bleaching systems on the ultrastructure of bovine dentin. Dent Traumatol 25:176–180

Cavalli V, Arrais CA, Giannini M, Ambrosano GM (2004) High-concentrated carbamide peroxide bleaching agents effects on enamel surface. J Oral Rehabil 31:155–159

Cavalli V, de Carvalho RM, Giannini M (2005) Influence of carbamide peroxide-based bleaching agents on the bond strength of resin-enamel/dentin interfaces. Braz Oral Res 19:23–29

Cavalli V, da Silva BG, Berger SB, Marson FC, Tabchoury CPM, Giannini M (2019) Decomposition rate, pH and enamel color change of bleaching agents at home and in the office. Braz Dent J 30:385–396

Cenci MS, Pereira-Cenci T, Donassollo TA, Sommer L, Strapasson A, Demarco FF (2008) Influence of thermal stress on marginal integrity of restorative materials. J Appl Oral Sci 16:106–110

Cintra LT, Benetti F, da Silva Facundo AC, Ferreira LL, Gomes-Filho JE, Ervolino E, Rahal V, Briso AL (2013) The number of bleaching sessions influence pulp tissue damage in rat teeth. J Endod 39:1576–1580

Cintra LTA, Benetti F, Ferreira LL, Gomes-Filho JE, Ervolino E, Gallinari MO, Rahal V, Briso AL (2016) Penetration capacity, color alteration and biological response of two in-office bleaching protocols. Braz Dent J 27:169–175

Costa CA, Riehl H, Kina JF, Sacono NT, Hebling J (2010) Human pulp responses to in-office tooth bleaching. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 109:59–64

Croll TP (2003) Bleaching sensitivity. J Am Dent Assoc 134:1163–1172

da Costa Filho LC, da Costa CC, Sória ML, Taga R (2002) Effect of home bleaching and smoking on marginal gingival epithelium proliferation: a histologic study in women. J Oral Pathol Med 31:473–480

de Alexandre RS, Sundfeld RH, Briso ALF, Valentino TA, Pinto CCM, Sundefeld MLMM (2006) Análise da Microdureza de Selantes de Fóssulas e Fissuras, quando Submetidos à Ação do Gel de Peróxido de Carbamida a 15%. J Bras Clín Odontol Integrada Saúde Bucal Coletiva. Edição Especia:01–06

de Almeida LC, Soares DG, Gallinari MO, de Souza Costa CA, Dos Santos PH, Briso AL (2015) Color alteration, hydrogen peroxide diffusion, and cytotoxicity caused by in-office bleaching protocols. Clin Oral Investig 19:673–680

De Arruda AM, dos Santos PH, Sundfeld RH, Berger SB, Briso AL (2012) Effect of hydrogen peroxide at 35% on the morphology of enamel and interference in the de-remineralization process: an in situ study. Oper Dent 37:518–525

De Munck J, Van Landuyt K, Coutinho E, Poitevin A, Peumans M, Lambrechts P, Van Meerbeek B (2005) Micro-tensile bond strength of adhesives bonded to class-I cavity-bottom dentin after thermo-cycling. Dent Mater 21:999–1007

Demarco FF, Meireles SS, Masotti AS (2009) Over-the-counter whitening agents: a concise review. Braz Oral Res 23:64–70

Donly KJ, Segura A, Sasa I, Perez E, Anastasia MK, Farrell S (2010) A controlled clinical trial to evaluate the safety and whitening efficacy of a 9.5% hydrogen peroxide high-adhesion whitening strip in a teen population. Am J Dent 23:292–296

Dudea D, Florea A, Mihu C, Câmpeanu R, Nicola C, Benga G (2009) The use of scanning electron microscopy in evaluating the effect of a bleaching agent on the enamel surface. Romanian J Morphol Embryol 50:435–440

Duque CCO, Soares DG, Basso FG, Hebling J, de Souza Costa CA (2017) Influence of enamel/dentin thickness on the toxic and esthetic effects of experimental in-office bleaching protocols. Clin Oral Investig 21:2509–2520

Esteves L, Fagundes TC, Dos Santos PH, da Silva L, de Alcântara S, Cintra L, Briso A (2022a) Does the bleaching gel application site interfere with the whitening result? A randomized clinical trial. Oper Dent 47:20–30

Esteves LMB, Dos Santos PH, Fagundes TC, de Oliveira GM, de Mello Antonaccio GB, Cintra LTÂ, Briso ALF (2022b) Effect of bleaching gel volume on color change and postoperative sensitivity: a randomized clinical study. Clin Oral Investig 26:2527–2536

Faraoni-Romano JJ, Silveira AG, Turssi CP, Serra MC (2008) Bleaching agents with varying concentrations of carbamide and/or hydrogen peroxides: effect on dental microhardness and roughness. J Esthet Restor Dent 20:395–404

Faraoni-Romano JJ, Turssi CP, Serra MC (2009) Effect of a 10% carbamide peroxide on wear resistance of enamel and dentine: in situ study. J Dent 37:273–278

Firat E, Ercan E, Gurgan S, Yucel OO, Cakir FY, Berker E (2011) The effect of bleachıng systems on the gingiva and the levels of IL-1β and IL-10 in gingival crevicular fluid. Oper Dent 36:572–580

Forner L, Salmerón-Sánchez M, Palomares M, Llena C, Amengual J (2009) The use of atomic force microscopy in determining the stiffness and adhesion force of human dentin after exposure to bleaching agents. J Endod 35:1384–1386

Freire A, Souza EM, de Menezes Caldas DB, Rosa EA, Bordin CF, de Carvalho RM, Vieira S (2009) Reaction kinetics of sodium ascorbate and dental bleaching gel. J Dent 37:932–936

Garcia EJ, Oldoni TL, Alencar SM, Reis A, Loguercio AD, Grande RH (2012) Antioxidant activity by DPPH assay of potential solutions to be applied on bleached teeth. Braz Dent J 23: 22–27

Ghalili KM, Khawaled K, Rozen D, Afsahi V (2014) Clinical study of the safety and effectiveness of a novel over-the-counter bleaching tray system. Clin Cosmet Investig Dent 6:15–19

Giniger M, Macdonald J, Ziemba S, Felix H (2005) The clinical performance of professionally dispensed bleaching gel with added amorphous calcium phosphate. J Am Dent Assoc 136: 383–392

Gokay O, Yilmaz F, Akin S, Tuncbilek M, Ertan R (2000) Penetration of the pulp chamber by bleaching agents in teeth restored with various restorative materials. J Endod 26:92–94

Gomes MN, Dutra H, Morais A, Sgura R, Devito-Moraes AG (2017) In-office bleaching during orthodontic treatment. J Esthe Restor Dent 29:83–92

Gurbuz A, Ozkan P, Yilmaz K, Yilmaz B, Durkan R (2013) Effect of at-home whitening strips on the surface roughness and color of a composite and an ormocer restorative material. J Prosthodont 22:69–73

Hannig C, Zech R, Henze E, Dorr-Tolui R, Attin T (2003) Determination of peroxides in saliva—kinetics of peroxide release into saliva during home-bleaching with Whitestrips and Vivastyle. Arch Oral Biol 48:559–566

Hannig C, Zech R, Henze E, Dreier S, Attin T (2005) Peroxide release into saliva from five different home bleaching systems in vivo. Am J Dent 18:13–18

Hasson H, Ismail AI, Neiva G (2006) Home-based chemically-induced whitening of teeth in adults. Cochrane Database Syst Rev 4:CD006202

Hayacibara MF, Ambrozano GM, Cury JA (2004) Simultaneous release of fluoride and aluminum from dental materials in various immersion media. Oper Dent 29:16–22

Haywood VB (2005) Treating sensitivity during tooth whitening. Compend Contin Educ Dent 26:11–20

Haywood VB, Heymann HO (1991) Nightguard vital bleaching. Quintessence Int 20:173–176

Haywood VB, Leonard RH, Dickinson GL (1997) Efficacy of six months of nightguard vital bleaching of tetracycline-stained teeth. J Esthet Dent 9:13–19

Hicks MJ, Silverstone LM, Flaitz CM (1984) A scanning electron microscopic and polarized light study of acid etching of caries like lesions in human enamel treated with sodium fluoride in-vitro. Arch Oral Biol 29:765–772

Hubbezoglu I, Akaoglu B, Dogan A, Keskin S, Bolayir G, Ozçelik S, Dogan OM (2008) Effect of bleaching on color change and refractive index of dental composite resins. Dent Mater J 27:105–116

Hunt RJ (1990) Behavioral and sociodemographic risk factors for caries. In: Bader JD (ed) Risk assessment in dentistry, vol 1990. University of North Carolina Dental Ecology, Chapel Hill, NC, pp 29–34

Jadad E, Montoya J, Arana G, Gordillo LAA, Palo RM, Loguercio AD (2011) Spectrophotometric evaluation of color alterations with a new dental bleaching product in patients wearing orthodontic appliances. Am J Orthod Dentofac Orthop 140:e43–e47

Jorgensen MG, Carroll WB (2002) Incidence of tooth sensitivity after home whitening treatment. J Am Dent Assoc 133:1076–1082

Kara HB, Aykent F, Ozturk B (2013) The effect of bleaching agents on the color stability of ceromer and porcelain restorative materials in vitro. Oper Dent 38:E1–E8

Kemaloğlu H, Tezel H, Ergücü Z (2014) Does post-bleaching fluoridation affect the further demineralization of bleached enamel? An in vitro study. BMC Oral Health 14:113

Kina JF, Huck C, Riehl H, Martinez TC, Sacono NT, Ribeiro APD, Costa CAS (2010) Response of human pulps after professionally applied vital tooth bleaching. Int Endod J 43:572–580

Kishta-Derani M, Neiva G, Yaman P, Dennison J (2007) In vitro evaluation of tooth-color change using four paint-on tooth whiteners. Oper Dent 32:394–398

Klukowska M, Götz H, White DJ, Zoladz J, Schwarz BO, Duschner H (2013) Depth profile analysis of non-specific fluorescence and color of tooth tissues after peroxide bleaching. Am J Dent 26:3–9

Kugel G, Gerlach RW, Aboushala A, Ferreira S, Magnuson B (2011) Long-term use of 6.5% hydrogen peroxide bleaching strips on tetracycline stain: a clinical study. Compend Contin Educ Dent 32:50–56

Kurzmann C, Verheyen J, Coto M, Kumar RV, Divitini G, Schokoohi-Tabrizi H, Verheyen P, De Moor RJG, Moritzab A, Agis H (2019) In vitro evaluation of experimental light-activated gels for tooth whitening. Photochem Photobiol Sci 18:1009–1019

Kwon YH, Huo MS, Kim KH, Kim SK, Kim YJ (2002) Effects of hydrogen peroxide on the light reflectance and morphology of bovine enamel. J Oral Rehabil 29:473–477

Kwon SR, Wang J, Oyoyo U, Li Y (2013) Evaluation of bleaching efficacy and erosion potential of four different over-the-counter bleaching products. Am J Dent 26:356–360

Leonard RH Jr, Bentley C, Eagle JC, Garland GE, Knight MC, Phillips C (2001) Nightguard vital bleaching: a long-term study on efficacy, shade retention. Side effects, and patients' perceptions. J Esthet Restor Dent 13:357–369

Li Q, Yu H, Wang Y (2009) Colour and surface analysis of carbamide peroxide bleaching effects on the dental restorative materials in situ. J Dent 37:348–356

Lo EC, Wong AH, McGrath C (2007) A randomized controlled trial of home tooth-whitening products. Am J Dent 20:315–318

Lucier RN, Etienne O, Ferreira S, Garlick JA, Kugel G, Egles C (2013) Soft-tissue alterations following exposure to tooth-whitening agents. J Periodontol 84:513–519

Markowitz K (2010) Pretty painful: why does tooth bleaching hurt? Med Hipotheses 74: 835–840

Marson FC, Sensi LG, Vieira LC, Araújo E (2008) Clinical evaluation of in-office dental bleaching treatments with and without the use of light-activation sources. Oper Dent 33:15–22

Marson FC, Gonçalves RS, Silva CO, Cintra LT, Pascotto RC, Santos PH, Briso AL (2015) Penetration of hydrogen peroxide and degradation rate of different bleaching products. Oper Dent 40:72–79

Matis BA (2003) Tray whitening: what the evidence shows. Compend Contin Educ Dent 24:354–362

Matis BA, Gaiao U, Blackman D, Schultz FA, Eckert GJ (1999) In vivo degradation of bleaching gel used in whitening teeth. J Am Dent Assoc 130:227–235

Matis BA, Yousef M, Cochran MA, Eckert GJ (2002) Degradation of bleaching gels in vivo as a function of tray design and carbamide peroxide concentration. Oper Dent 27:12–18

May LG, Salvia AC, Souza RO, Michida SM, Valera MC, Takahashi FE, Bottino MA (2010) Effect of sodium ascorbate and the time lapse before cementation after internal bleaching on bond strength between dentin and ceramic. J Prosthodont 19:374–380

Meireles SS, Santos IS, Bona AD, Demarco FF (2010) A double-blind randomized clinical trial of two carbamide peroxide tooth bleaching agents: 2-year follow-up. J Dent 38:956–963
Minoux M, Serfaty R (2008) Vital tooth bleaching: biologic adverse effects-a review. Quintessence Int 39:645–659
Moraes RR, Marimon JL, Schneider LF, Correr Sobrinho L, Camacho GB, Bueno M (2006) Carbamide peroxide bleaching agents: effects on surface roughness of enamel, composite and porcelain. Clin Oral Investig 10:23–28
Mourouzis P, Koulaouzidou EA, Helvatjoglu-Antoniades M (2013) Effect of in-office bleaching agents on physical properties of dental composite resins. Quintessence Int 44:295–302
Naik S, Tredwin CJ, Scully C (2006) Hydrogen peroxide tooth-whitening (bleaching): review of safety in relation to possible carcinogenesis. Oral Oncol 42:668–674
Oda D, Nguyen MP, Royack GA, Tong DC (2001) H2O2 oxidative damage in cultured oral epithelial cells: the effect of short-term vitamin C exposure. Anticancer Res 21:2719–2724
Owens BM, Rowland CC, Brown DM, Covington JS (1998) Postoperative dental bleaching: effect of microleakage on class V tooth colored restorative materials. J Tenn Dent Assoc 78:36–40
Palé M, Mayoral JR, Llopis J, Vallès M, Basilio J, Roig M (2014) Evaluation of the effectiveness of an in-office bleaching system and the effect of potassium nitrate as a desensitizing agent. Odontology 102:203–210
Paravina RD, Pérez MM, Ghinea R (2019) Acceptability and perceptibility thresholds in dentistry: a comprehensive review of clinical and research applications. J Esthet Restor Dent 31(2):103–112
Patri G, Agnihotri Y, Rao SR, Lakshmi N, Das S (2013) An in vitro spectrophotometric analysis of the penetration of bleaching agent into the pulp chamber of intact and restored teeth. J Clin Diagn Res 7:3057–3059
Paula AB, Dias MI, Ferreira MM, Carrilho T, Marto CM, Casalta J, Cabrita AS, Carrilho E (2015) Effects on gastric mucosa induced by dental bleaching - an experimental study with 6% hydrogen peroxide in rats. J Appl Oral Sci 23:497–507
Perdigão J (2010) Dental whitening – revisiting the myths. Northwest Dent 89(19–21):23–26
Pinto VG (2001) Saúde bucal coletiva. Santos, São Paulo
Polydorou O, Hellwig E, Auschill TM (2007a) The effect of at-home bleaching on the microhardness of six esthetic restorative materials. J Am Dent Assoc 138:978–984
Polydorou O, Monting JS, Hellwig E, Auschill TM (2007b) Effect of in-office tooth bleaching on the microhardness of six dental esthetic restorative materials. Dent Mater 23:153–158
Powell LV, Bales DJ (1991) Tooth bleaching: its effect on oral tissues. J Am Dent Assoc 122: 50–54
Price RB, Sedarous M, Hiltz GS (2000) The pH of tooth-whitening products. J Can Dent Assoc 66:421–426
Rahal V, Azevedo FA, Gallinari MO, Silva NM, Gonçalves RS, Cintra LTA, Marson FC, Briso ALF (2014) Avaliação sensorial quantitativa da sensibilidade dentária com o uso de um dessensibilizante. Rev Dental Press de Estét 11:108–117
Rahal V, Gallinari MO, Barbosa JS, Martins-Junior RL, Santos PH, Cintra LTA, Briso ALF (2018) Influence of skin cold sensation threshold in the occurrence of dental sensitivity during dental bleaching: a placebo controlled clinical trial. J App Oral Sci 26:e20170043
Rodrigues JA, Marchi GM, Ambrosano GM, Heymann HO, Pimenta LA (2005) Microhardness evaluation of in situ vital bleaching on human dental enamel using a novel study design. Dent Mater 21:1059–1067
Sasaki RT, Arcanjo AJ, Flório FM, Basting RT (2009) Micromorphology and microhardness of enamel after treatment with home-use bleaching agents containing 10% carbamide peroxide and 7.5% hydrogen peroxide. J Appl Oral Sci 17:611–616
Schemehorn B, González-Cabezas C, Joiner A (2004) A SEM evaluation of a 6% hydrogen peroxide tooth whitening gel on dental materials in vitro. J Dent 1:35–39
Severcan F, Gokduman K, Dogan A, Bolay S, Gokalp S (2008) Effects of in-office and at-home bleaching on human enamel and dentin: an in vitro application of Fourier transform infrared study. Appl Spectrosc 62:1274–1279

Silva MD, Davies RM, Stewart B, DeVizio W, Tonholo J, da Silva Júnior JG, Pretty IA (2006) Effect of whitening gels on the surface roughness of restorative materials in situ. Dent Mater 22:919–924

Simões RC, Soares D, de Souza Costa CA, Santos PD, Cintra L, Briso A (2015) Effect of different light sources and enamel preconditioning on color change, H_2O_2 penetration, and cytotoxicity in bleached teeth. Oper Dent 41:83–92

Soares DG, Ribeiro AP, Sacono NT, Loguércio AD, Hebling J, Costa CA (2013a) Mineral loss and morphological changes in dental enamel induced by a 16% carbamide peroxide bleaching gel. Braz Dent J 24:517–521

Soares DG, Ribeiro AP, Lima AF, Sacono NT, Hebling J, de Souza Costa CA (2013b) Effect of fluoride-treated enamel on indirect cytotoxicity of a 16% carbamide peroxide bleaching gel to pulp cells. Braz Dent J 24:121–127

Soares DG, Basso FG, Hebling J, de Souza Costa CA (2014a) Concentrations of and application protocols for hydrogen peroxide bleaching gels: effect on pulp cell viability and whitening efficacy. J Dent 42:185–198

Soares DG, Basso FG, Pontes EC, Garcia Lda F, Hebling J, de Souza Costa CA (2014b) Effective tooth-bleaching protocols capable of reducing H_2O_2 diffusion through enamel and dentine. J Dent 42:351–358

Soutomaior J (2019) Effectiveness of light sources on in-office dental bleaching: a systematic review and meta-analyses. Oper Dent 44:105–107

Spalding M, Taveira LA, de Assis GF (2003) Scanning electron microscopy study of dental enamel surface exposed to 35% hydrogen peroxide: alone, with saliva, and with 10% carbamide peroxide. J Esthet Restor Dent 15:154–164

Steinberg D, Mor C, Dogan H, Zacks B, Rotstein I (1999) Effect of salivary biofilm on the adherence of oral bacteria to bleached and non-bleached restorative material. Dent Mater 15:14–20

Sulieman MA (2008) An overview of tooth-bleaching techniques: chemistry, safety and efficacy. Periodontol 2000(48):148–169

Sulieman M, Addy M, MacDonald E, Rees JS (2004) The effect of hydrogen peroxide concentration on the outcome of tooth whitening: an in vitro study. J Dent 32:295–299

Swift EJ Jr, Heymann HO, Wilder AD Jr, Barker ML, Gerlach RW (2009) Effects of duration of whitening strip treatment on tooth color: a randomized, placebo-controlled clinical trial. J Dent 37:e51–e56

Taher NM (2005) The effect of bleaching agents on the surface hardness of tooth colored restorative materials. J Contemp Dent Pract 6:18–26

Tay LY, Kose C, Loguercio AD, Reis A (2009) Assessing the effect of a desensitizing agent used before in-office tooth bleaching. J Am Dent Assoc 140:1245–1251

Tipton DA, Braxton SD, Dabbous MK (1995) Role of saliva and salivary components as modulators of bleaching agent toxicity to human gingival fibroblasts in vitro. J Periodontol 66:766–774

Torabi K, Rasaeipour S, Ghodsi S, Khaledi AA, Vojdani M (2014a) Evaluation of the effect of a home bleaching agent on surface characteristics of indirect esthetic restorative materials - part II microhardness. J Contemp Dent Pract 5:438–443

Torabi K, Rasaeipour S, Khaledi AA, Vojdani M, Ghodsi S (2014b) Evaluation of the effect of a home-bleaching agent on the surface characteristics of indirect esthetic restorative materials: part I - roughness. J Contemp Dent Pract 15:326–330

Trentino AC, Soares AF, Duarte MA, Ishikiriama SK, Mondelli RF (2015) Evaluation of pH levels and surface roughness after bleaching and abrasion tests of eight commercial products. Photomed Laser Surg 33:372–377

Türker SB, Biskin T (2002) The effect of bleaching agents on the microhardness of dental aesthetic restorative materials. J Oral Rehabil 29:657–661

Türker SB, Biskin T (2003) Effect of three bleaching agents on the surface properties of three different esthetic restorative materials. J Prosthet Dent 89:466–473

Ulukapi H, Benderli Y, Ulukapi I (2003) Effect of pre- and postoperative bleaching on marginal leakage of amalgam and composite restorations. Quintessence Int 34:505–508

Vargas FDAS, Soares DG, Basso FG, Hebling J (2014) Dose-response and time-cours αtocoferol mediating the cytoprotection of dental pulp cells against hydrogen peroxide. Braz Dent J 25:367–371

Vongsavan N, Matthews B (1991) The permeability of cat dentine in vivo and in vitro. Arch Oral Biol 36:641–646

Ward M, Felix H (2012) A clinical evaluation comparing two H2O2 concentrations used with a light-assisted chairside tooth whitening system. Compend Contin Educ Dent 33:286–291

Wattanapayungkul P, Matis BA, Cochran MA, Moore BK (1999) A clinical study of the effect of pellicle on the degradation of 10% carbamide peroxide within the first hour. Quintessence Int 30:737–741

White DJ, Duschner H, Pioch T (2008) Effect of bleaching treatments on microleakage of class I restorations. J Clin Dent 19:33–36

Williams HA, Rueggeberg FA, Meister LW (1992) Bleaching the natural dentition to match the color of existing restorations: case reports. Quintessence Int 23:673–677

Willmot DR (2004) White lesions after orthodontic treatment: does low fluoride make a difference? J Orthod 31:235–242

Xu X, Zhu L, Tang Y, Wang Y, Zhang K, Li S, Bohman LC, Gerlach RW (2007) Randomized clinical trial comparing whitening strips, paint-on gel and negative control. Am J Dent 20:28A–31A

Yalcin F, Gurgan S (2005) Effect of two different bleaching regimens on the gloss of tooth-colored restorative materials. Dent Mater 21:464–468

Yousaf A, Aman N, Manzoor MA, Shah JA (2014) Dilrasheed postoperative sensitivity of self-etch versus total etch adhesive. J Coll Physicians Surg Pak 24:383–386

Yudhira R, Peumans M, Barker ML, Gerlach RW (2007) Clinical trial of tooth whitening with 6% hydrogen peroxide whitening strips and two whitening dentifrices. Am J Dent 20:32A–36A

Zhu T, Lim BS, Park HC, Son KM, Yang HC (2012) Effects of the iron-chelating agent deferoxamine on triethylene glycol dimethacrylate, 2-hydroxylethyl methacrylate, hydrogen peroxide-induced cytotoxicity. J Biomed Mater Res B Appl Biomater 100:197–205

Human Pulpal Responses to Peroxides

5

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Abstract

Most patients subjected to professional tooth bleaching report posttreatment hypersensitivity that varies from slight to intolerable. The pathway for bleaching-induced tooth sensitivity is associated with the capability of the main active component of bleaching gels, hydrogen peroxide (H_2O_2), to diffuse through enamel and dentin to reach the pulp tissue. Since H_2O_2 is a reactive oxygen species (ROS) with intense oxidative potential, the contact of this molecule with the pulp tissue promotes oxidative cell damage, leading to local connective inflammation that triggers nociceptive stimulus. However, as this clinical symptom is transient, it is still unclear how relevant this adverse effect is to the pulp-dentin complex. Thus, in this chapter, the authors describe relevant clinical and laboratory data currently provided by several in vitro and in vivo studies evaluating traditional

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in-office (professional) and at-home bleaching therapies and discuss alternative tooth bleaching protocols that may prevent or at least minimize the harmful effects of these oxidative esthetic treatments to the pulp tissue vitality.

5.1 Introduction

Despite the well-known role played by hydrogen peroxide (H_2O_2) on oxidative cell stress and induction of inflammatory tissue reactions, this molecule has been widely used as the main active principle for bleaching therapies performed in vital teeth. The results of randomized clinical trials for a wide array of bleaching products have shown that many patients undergoing H_2O_2-based bleaching therapies complain of tooth sensitivity (Reis et al. 2011, 2013; He et al. 2012; Tay et al. 2012; Santana et al. 2014; de Paula et al. 2015).

Overall, to be regarded as an esthetically effective therapy, the H_2O_2 present in the bleaching gels must diffuse through the enamel to reach the dentin substrate, in which the intrinsic pigments (chromophores) are mainly located. This effect is possible because H_2O_2 features high chemical stability compared to other ROS due to its low oxidation potential. When diffusing through the enamel and reaching dentin, the H_2O_2 molecules break down into water and oxygen, releasing free radicals with higher oxidation potential and very short half-life (e.g., the hydroxyl radical and the superoxide anion) capable of promoting effective in situ chromogen decomposition. However, dentin is a permeable tubular substrate that provides an easy pathway for the diffusion of non-reacted H_2O_2 toward the pulp chamber. Indeed, several laboratory studies (Gokay et al. 2000; Gokay et al. 2004; Gokay et al. 2005; Camargo et al. 2007; Ubaldini et al. 2013) have demonstrated that high concentrations of residual H_2O_2 remain undissociated within mineralized tooth structures and that these non-reacted molecules can reach pulp cells. According to these studies, the higher the concentration of H_2O_2 on the bleaching gel and the contact time with tooth structure, the higher the detection of residual H_2O_2 inside the pulp chamber.

The presence of high concentration of H_2O_2 in the extracellular environment is dangerous since this molecule can pass through cellular membranes. Once in the cytoplasm, H_2O_2 may be dissociated into several toxic free radicals, leading to an oxidative stress condition that has been related to variable cellular alterations and, ultimately, cell death. The sensitivity of cells to undergo oxidative stress during periods of high ROS exposure appears to be cell-type specific. For instance, human dental pulp cells feature a high sensitivity to oxidative stress mediated by H_2O_2 in vitro. However, the same amount of H_2O_2 capable of causing complete depletion of human dental pulp cell viability has no significant toxic effect on human gingival fibroblasts and other cell lineages (Zhu et al. 2012). Consequently, to better understand the biological effects of residual H_2O_2 released from bleaching gels on pulp tissue, our research group has conducted innovative laboratory studies using artificial pulp chambers and histopathological investigations in human teeth. This chapter overviews the laboratory and clinical scientific data from these studies.

5.2 In-Office Bleaching Mediated Toxicity on Dental Pulp Cells

About 86–90% of patients subjected to professional in-office bleaching therapy, in which bleaching gels with 30–40% H_2O_2 are applied onto the enamel for 30–60 min at each session, report post-bleaching tooth sensitivity (Tay et al. 2012; Santana et al. 2014). The intensity of such adverse effect varies from moderate to severe in around 60% of cases (Fig. 5.1) (Tay et al. 2012). The prevalence of tooth sensitivity may reach 100% when traditional in-office therapy is associated with light sources with 200 mW intensity and laser diodes of wavelengths at 470 nm and 830 nm aimed at activating the bleaching gel through heating (Reis et al. 2011).

Clinical studies have demonstrated that the prevalence and intensity of tooth sensitivity are restricted to anterior teeth and proportional to the tooth size, with incisors being the most susceptible teeth (de Almeida et al. 2012; Bonafé et al. 2013). Therefore, the toxic potential of traditional in-office therapy on pulp cells has been the focus of several preliminary studies carried out by our research group. When a 35% H_2O_2 gel was applied for three consecutive periods of 15 min onto 3.5-mm-thick enamel/dentin discs (simulating lower central incisors) adapted to artificial pulp chambers (APC), gel components that diffused through the dental structure (extract) caused toxic effects to pulp cells. In such laboratory studies, the extracts were applied to the cells for 1 or 24 h. After a 1-h contact interval, the

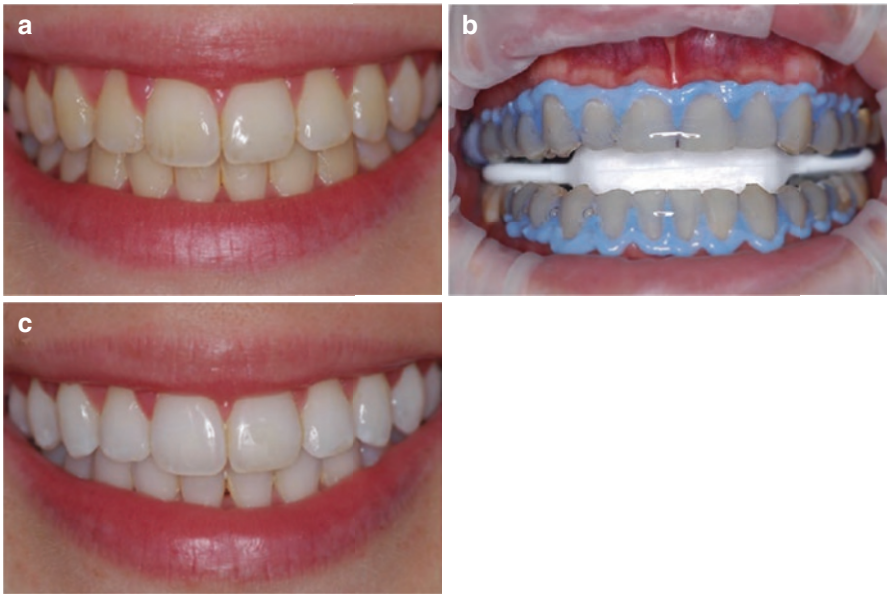

Fig. 5.1 Patient (**a**) subjected to professional in-office tooth bleaching therapy (**b**), which can be esthetically regarded as a success (**c**). However, the patient reported post-bleaching sensitivity in the anterior teeth. (Courtesy of Dr. Heraldo Riehl)

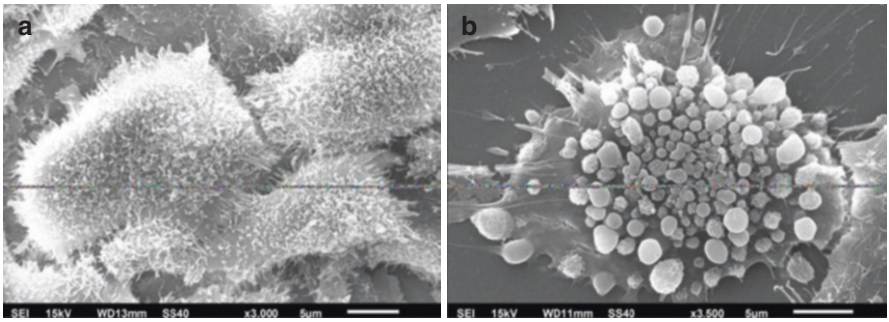

Fig. 5.2 (**a**) Scanning electron micrograph showing the morphology of normal odontoblast-like MDPC-23 cells. Original magnification = ×3000. (**b**) Scanning electron micrograph showing a MDPC-23 cell exposed for 1 h to the extract obtained after simulated traditional in-office bleaching therapy. Original magnification = ×3500

odontoblast-like cells, an immortalized cell lineage from rat dental papillae, featured 50 to 60% of cell viability reduction (Soares et al. 2013a; Duque et al. 2014; de Almeida et al. 2015a; Soares et al. 2015a). Almost 100% of cell viability reduction was observed after 24-h exposure of pulp cells to these extracts (Coldebella et al. 2009; Trindade et al. 2009). Cell morphology was completely disturbed, with cells showing apoptotic bodies-like structures, as shown in Fig. 5.2. Human dental pulp cells exposed to the bleaching gel extracts were even more vulnerable, corroborating data previously reported in the literature. Around 97% of cell viability reduction was observed in human pulp cells after only 1-h contact with extracts.

The intensity of the damaging effects caused by the 35% H_2O_2 bleaching gel on pulp cells was proportional to their contact time with dental structure, which was directly related to the amount of H_2O_2 capable of diffusing through enamel/dentin discs (Soares et al. 2013b; Duque et al. 2014; Soares et al. 2015a). Another important and interesting aspect is that the low pigmentation of enamel/dentin discs with 2.3 mm in thickness favored the trans-amelodentinal diffusion of H_2O_2 that increased the cytotoxic results caused by in-office bleaching protocols (de Oliveira Duque et al. 2020). Even though data from laboratory studies cannot be extrapolated directly to clinical situations, these findings indicate that bleaching protocols can be even more harmful when less pigmented teeth are submitted to professional bleaching therapy. In addition, associating the in-office bleaching technique with some specific light sources may increase the cytotoxicity because light sources enhance the H_2O_2 diffusion through tooth structure (Camargo et al. 2009).

According to our data, pulp cell viability reduction after tooth bleaching seems to be associated with rupture of the cell membrane and generation of oxidative stress in a time-/concentration-dependent fashion. These effects are proportional to the H_2O_2 dosage capable of reaching the cells, with high concentrations leading to cell death by necrosis following two pathways: (1) direct contact with free radicals from extracellular H_2O_2 decomposition, leading to cell membrane rupture, and (2) the onset of a pathologic oxidative stress condition after H_2O_2 diffusion through the

cell membrane and further decomposition into free radicals on cytoplasm, culminating in lipid peroxidation (Soares et al. 2014a, b).

Since the amount of H_2O_2 capable of reaching cells after trans-enamel and transdentinal diffusion is the main pathway for bleaching-induced cell toxicity, reducing this phenomenon is highly required to minimize the oxidative damage on pulp cells, turning bleaching therapy into a safe procedure compatible with pulp health. Decreasing the H_2O_2 concentration in the bleaching gel by 50% and applying the gel from 5 to 45 min on the enamel may decrease by 11.3- to 4.5-fold, respectively, the toxicity of in-office tooth bleaching to pulp cells compared with the traditional therapy (35% H_2O_2 3 × 15 min) (Soares et al. 2014a). Using these alternative protocols with a 17.5% H_2O_2 gel allowed pulp cells to overcome the low initial oxidative damage and feature a regenerative phenotype throughout time (Soares et al. 2014a, c).

Both oxidative stress intensity and dosage of pro-inflammatory mediators are inversely related to pulp tissue regeneration capability. The degree of disturbance on the expression of odontoblastic markers (ALP, DSPP, DMP1, and mineralized nodule deposition) after tooth bleaching relates to the oxidative stress intensity and the upregulation of IL-1β, TNF-α, IL-6, IL-17, IL-23, and COX-2 on remaining cells (Soares et al. 2014b; Soares et al. 2015c, Benetti et al. 2018, da Silva et al. 2022). Exposure of human dental pulp cells to high doses of pro-inflammatory mediators, such as TNF-α and IL1-β, may negatively interfere with their odontoblastic marker expression and mineralization rate, whereas low dosages seem to have the opposite effect (Min et al. 2006; Paula-Silva et al. 2009; Alongi et al. 2010). Human dental pulp cells under intense oxidative stress triggered by long-term exposure to H_2O_2 had the expression of DSPP and DMP1 downregulated, associated with no mineralized matrix deposition. Conversely, cells treated with nontoxic H_2O_2 concentrations enhanced ALP activity, DSPP, OPN, and OCN expression and calcified nodule deposition (Lee et al. 2006, 2013; Min et al. 2008; Matsui et al. 2009).

Therefore, the lower the concentration of H_2O_2 in contact with pulp cells after tooth bleaching, the higher the regenerative capability of human pulp tissue to overcome oxidative damage**.**

From this perspective, studies performed in the last few years have focused on development and assessment of innovative strategies for reducing the amount of residual H_2O_2 and other free radicals capable of diffusing through the dental structure to reach the pulp chamber, since these toxic molecules play a central role in pulp tissue damage. Bleaching gels containing 8 to 10% H_2O_2 can significantly minimize the initial toxicity in human dental pulp cells (Soares et al. 2015a). Additionally, these bleaching gels promoted tooth color alterations statistically similar to those observed when high concentrated gels were used (de Oliveira Duque et al. 2017). More recently, it has been reported that the volume of whitening gel applied to the tooth structure significantly affects the degree of posttreatment sensitivity (Esteves et al. 2022).

Therefore, tailoring the bleaching regimen to the tooth size appears to be an interesting alternative to achieve an effective, safe, and biocompatible in-office bleaching technique.

5.3 Effects of At-Home Bleaching on Pulp Cells In Vitro

The at-home bleaching therapy with 10% carbamide peroxide (CP) agents has been considered the safest method for tooth bleaching since minimal clinical adverse effects have been reported (Boushell et al. 2012). Applying 10% CP gel from 1.5 to 8 h on dental structure does not result in significant toxic effects on odontoblast-like cells and human dental pulp cells (Soares et al. 2011; Lima et al. 2013; Almeida et al. 2015). Also, applying 10% CP gel for 4 h onto 3.5 mm enamel/dentin discs results in 16 times less intense H_2O_2 diffusion than the traditional in-office bleaching protocol, i.e., 35% H_2O_2 gel 3 × 15 min (Duque et al. 2014). Conversely, increasing CP concentration from 10 to 16% increases the toxicity caused by this esthetic therapy to pulp cells (Soares et al. 2011). Taking into consideration that clinical studies have demonstrated that higher concentrations of CP gels cause the same bleaching outcome as that achieved by using 10% CP gel (Meireles et al. 2010), the use of higher concentration products has no advantage and may be more toxic to pulp tissue. Nonetheless, higher CP concentrations (15 to 22%) are available for at-home tooth bleaching with the appeal of promoting a faster bleaching outcome.

H_2O_2-based at-home bleaching products are also available. The application of 6% H_2O_2 gels from 45 min to 1.5 h causes no toxic effects on odontoblast-like cells. However, the amount of H_2O_2 capable of diffusing through dental structure and interacting with the cells was twice higher compared to that of 10% CP gel (Almeida et al. 2015). Also, a 10% H_2O_2 whitening strip (WS) applied for 1 h on tooth structure did not cause trans-enamel and trans-dentinal cytotoxicity to this same pulp cell lineage. The WS resulted in about 13 times lower H_2O_2 diffusion than that observed for traditional in-office bleaching therapy with the 35% H_2O_2 gel (Soares et al. 2013a). Despite the interesting results obtained with WS, this treatment is currently carried out without direct professional supervision. Therefore, there is a risk of overuse associated with this over the counter at-home bleaching technique, which, in turn, may cause higher toxic effects on pulp cells. Evidence indicates the WS and CP toxic effect is time-dependent, increasing significantly after 1-h daily application for five consecutive days (Lima et al. 2013; Soares et al. 2013b). The main concern regarding at-home bleaching relies on the fact that it is a patient-applied therapy. Therefore, there is a risk of gel application on exposed dentin areas, craze lines, and restoration interfaces, which may increase H_2O_2 diffusion through mineralized tooth structures. In addition, the inadequate use of the tray may result in gel overflow, with extended soft tissue exposure and potential ingestion of the material.

In this way, all bleaching protocols, including at-home bleaching, must undergo professional supervision. Also, the professional should perform a detailed clinical evaluation before prescribing this therapy.

5.4 Histopathological Analysis of Human Dental Pulp After In-Office Bleaching

Based on data from in vitro studies, high concentrations of H_2O_2 within the pulp chamber are responsible for the intense oxidative stress condition that causes cell membrane disruption associated with pulp cell death by necrosis (Soares et al. 2015b, c, d; Soares et al. 2016a). This cytotoxic effect also extensively damages neighboring tissues since lysosome enzymes and other metabolites are leached from dying cells, causing a ripple effect. Consequently, an acute inflammatory reaction is expected resulting in the expression and synthesis of a plethora of pro-inflammatory cytokines and chemokines, followed by hyperalgesia mediators, such as prostaglandins (Cooper et al. 2010; Markowitz et al. 2010; Pashley 2013; Cooper et al. 2014). These cellular events have been associated with the clinical symptoms of tooth sensitivity. To detect these events on human pulp tissue, our research group has conducted histopathological analysis on human teeth subjected to professional in-office bleaching therapies. In many of these studies, we included sound premolars and mandibular incisors scheduled for extraction for orthodontic reasons under respective approval by ethical committees. Therefore, the participants (or legal guardians for patients under 18 years of age) received all necessary explanations, including the experiment rationale, the clinical procedures to be performed, and possible risks. All patients signed a consent form explaining the research protocol.

When a bleaching gel with high concentration of 38% H_2O_2 was applied three times for 10 min each to sound mandibular incisors from young patients (mean age 16.2 years), intense pulpal damage occurred in about 75% of teeth. Pulp necrosis was observed in a wide area of the coronal pulp tissue. Deposition of tertiary dentin in part of the coronal and root pulp tissue associated with mild local inflammatory response was also detected in bleached incisors (Fig. 5.3).

On the other hand, pulps of premolars subjected to the same bleaching protocol with 38% H_2O_2 gel showed the following histopathologic features: tubular dentin and predentin, intact odontoblastic layer, cell-free zone, and cell-rich zone, such as observed in intact control groups (non-bleached incisors and premolars) (control teeth—Fig. 5.4).

In this experiment, the mean of dentin thickness was 1.82 ± 0.08 mm for bleached incisors and 3.10 ± 0.11 mm for bleached premolars. Only patients who had their incisors bleached reported tooth sensitivity (de Souza Costa et al. 2010). Similar results were found when sound mandibular incisors (mean age 18.2 years) were bleached with a 35% H_2O_2 gel applied on enamel for three consecutive periods of 15 min each or one period of 45 min. Similar pulp tissue responses were found for both tested protocols with the 35% H_2O_2 gel. Most bleached incisors (80%)

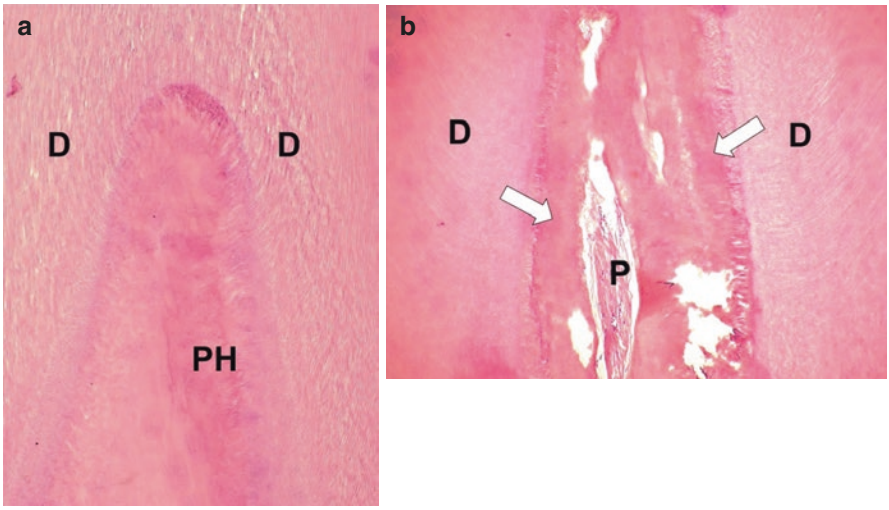

Fig. 5.3 (**a**) Pulp horn (PH) of a human lower incisor subjected to a professional in-office bleaching with 38% H_2O_2. Note the large area of necrosis. H/E, ×64. (**b**) Intense deposition of tertiary dentin is observed (arrows) in the radicular pulp chamber, in which a small area of residual pulp (P) tissue with inflammation can be seen. H/E, ×64. (D = dentin)

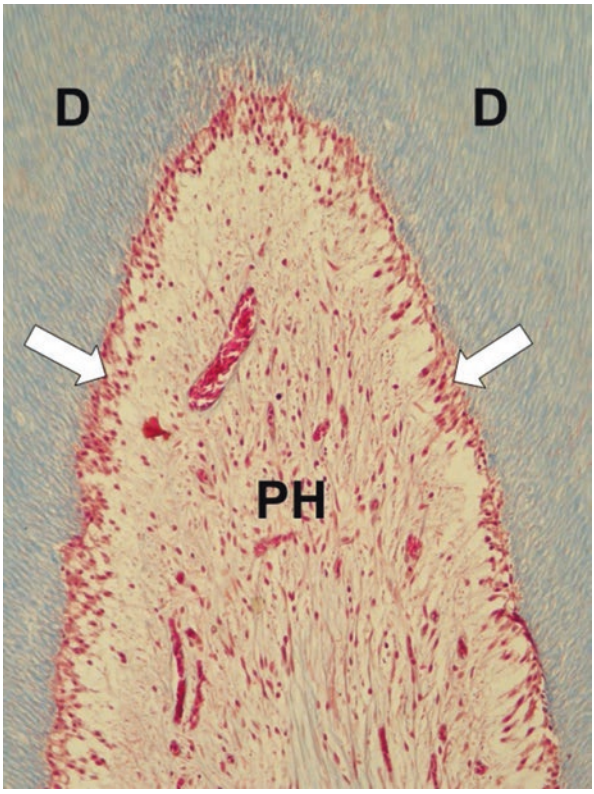

Fig. 5.4 Pulp horn (PH) of a human tooth exhibiting normal histological features. Note the odontoblasts (arrows) underlying the tubular dentin (D) and the subjacent cell-free zone. A number of small blood vessels among collagen fibers and fibroblasts can be observed. Masson's trichrome, ×125

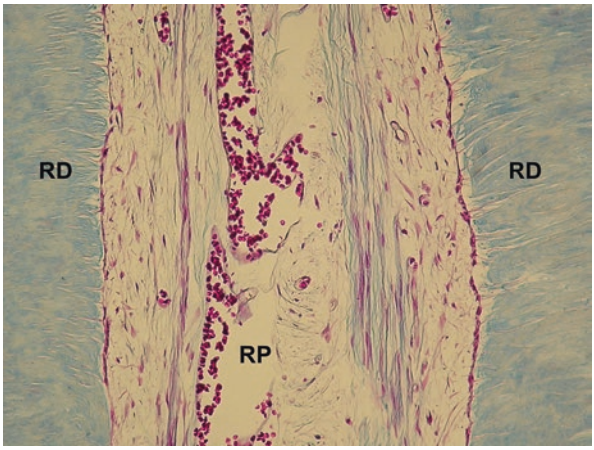

Fig. 5.5 Radicular pulp (RP) tissue of a bleached human lower incisor. Note the lateral deposition of reactionary dentin (RD), which exhibits a reduced number of tubules with cytoplasm processes within them. Masson's trichrome, ×180

exhibited a large zone of coagulation necrosis in the coronal pulp tissue associated with mild/moderate inflammatory response on the surrounding tissue. Tertiary dentin adjacent to the necrotic tissue was observed in 25% of those teeth, associated with tertiary dentin in the lateral walls of the coronal and root pulp chambers (Fig. 5.5). Moderate deposition of tertiary dentin with no coronal pulp necrosis occurred in only 20% of the samples, which exhibited mild inflammatory pulp reaction. All patients subjected to bleaching protocol reported tooth sensitivity (Roderjan et al. 2014, 2015).

These data corroborate those obtained from clinical investigations, in which the authors demonstrated that tooth sensitivity is restricted to anterior teeth subjected to in-office bleaching (de Almeida et al. 2012; Bonafé et al. 2013). According to these authors, teeth bleached with 35% H_2O_2 gel applied on enamel for three consecutive periods of 15 min each had tooth sensitivity in 76.6% of lateral incisors, 53.3% of central incisors, and 30% of canines, with no discomfort reports for premolars. Thus, one can conclude that enamel/dentin thickness plays an important role in H_2O_2 diffusion through mineralized tooth structures to reach pulp chamber, causing tissue damage and post-bleaching sensitivity more intensely in anterior than posterior teeth.

Another investigation showed that partial pulp necrosis occurred in 60% of mandibular incisors of elderly patients (54–62 years old; mean 58.2 ± 4.3) in comparison with 100% of young patients (18 to 30 years old; mean 20.1 ± 4.3) that were bleached using the same in-office bleaching therapy. Additionally, the areas of pulp necrosis were larger in young teeth. The mean dentin thickness in elderly and young patients was 1.77 ± 0.08 mm and 1.99 ± 0.10 mm, respectively. As observed in the previous study, the histological sections evidenced differentiated odontoblast-like cells that deposited a layer of reactionary dentin below the necrotic area. These pulp responses to bleaching products are similar to those observed after calcium hydroxide application on mechanically exposed pulps of sound teeth.

Therefore, it seems that even in human pulps that are strongly damaged by in-office tooth bleaching procedures, the pulp cells subjacent to the necrotic tissue can

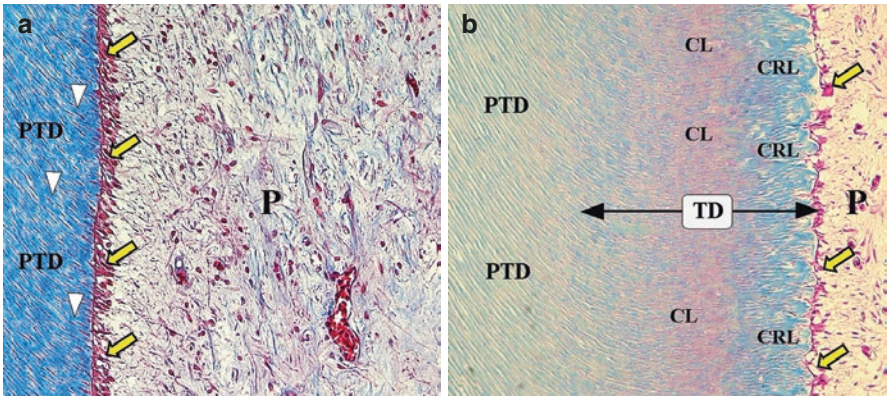

Fig. 5.6 (**a**) Pulp-dentin complex of the cervical zone of a sound human premolar submitted to conventional in-office bleaching. A continuous layer odontoblasts (arrows) underlying the primary tubular dentin (PTD) is observed. Note that the cytoplasm processes from the odontoblasts are present inside the dentinal tubules (head arrows). The subjacent pulp tissue (P) exhibits normal histological characteristics. Masson's trichrome, ×180. (**b**) Pulp-dentin complex of the cervical zone of a sound human lower incisor submitted to conventional in-office bleaching. The odontoblast layer has a reduced number of cells (arrows). Between the pulp tissue (P) and the primary tubular dentin (PTD), a thick layer of tertiary dentin (TD) is observed. Note that the TD exhibits a calcified layer (CL) and a collagen-rich layer (CRL). Masson's trichrome, ×180

maintain their phenotype, confirming the data collected in previous in vitro studies conducted by our research group (Fig. 5.6).

Based on these data, tooth sensitivity experienced by patients subjected to in-office bleaching with 35–38% H_2O_2 may be associated with an inflammatory reaction caused by oxidizing compounds from bleaching gels capable of reaching the pulp chamber in toxic concentrations, producing an intense chemical irritation of pulp cells. Because in-office tooth bleaching causes pulp damage, the release of cell-derived factors, such as prostaglandins, would excite or sensitize pulpal nociceptors. Additionally, we believe that the fluid shifts that occur in dentinal tubules due to vasodilation and increased pulp pressure during local tissue inflammation may trigger impulses in the intradentinal pulpal nerve fiber endings, causing the intense tooth sensitivity that has been claimed by patients subjected to this professional in-office therapy. Further studies are needed to clarify this topic.

5.5 Tooth/Restoration Interface as a Pathway for Bleaching Inducing Toxicity

Clinical trials showed an increased tooth sensitivity when traditional in-office tooth bleaching is performed in anterior teeth restored with adhesive restorations without clinical signs of margin degradation (Bonafé et al. 2013). The presence of restorations in the tooth to be bleached may increase H_2O_2 diffusion into the pulp chamber (Soares et al. 2022). In addition, restorative dental materials interfere significantly

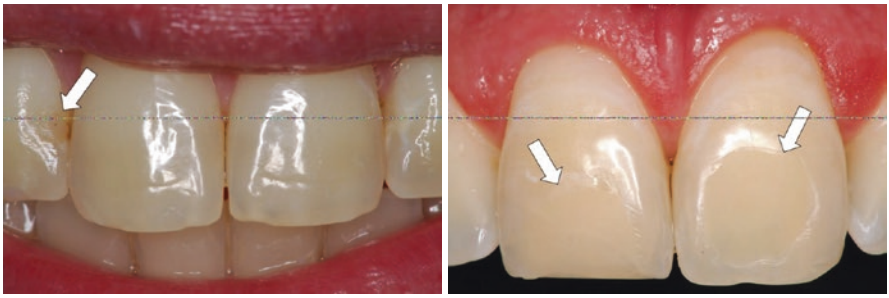

Fig. 5.7 Anterior restored teeth that were selected by a clinician for professional bleaching. (Images provided by Dr. Heraldo Riehl)

with this H_2O_2 diffusion through enamel and dentin (Gokay et al. 2000; Benetti et al. 2004; Gokay et al. 2004; Camargo et al. 2007). Therefore, as several restorative materials and bleaching protocols are available in clinical practice, the question related to the safety of tooth bleaching performed in restored teeth remains a concern (Fig. 5.7).

Previous studies demonstrated that different adhesive systems have variable degrees of susceptibility to H_2O_2: one-step self-etch > two-step self-etch > etch-and-rinse systems (Van Landuyt et al. 2009; Didier et al. 2013; Dudek et al. 2013; Roubickova et al. 2013). According to the results collected in our laboratory, interfaces of self-etch adhesive act as a pathway for H_2O_2 diffusion from the tooth surface into the pulp chamber, increasing the toxicity of a 35% H_2O_2 gel on pulp cells (Soares et al. 2015d) and upregulating pro-inflammatory cytokines COX-2, IL-6, and TNF-α (Soares et al. 2022). Nevertheless, no significant difference concerning cytotoxicity and trans-enamel and trans-dentinal diffusion of H_2O_2 was observed when etch-and-rinse adhesive restorations were bleached with 20 or 35% H_2O_2 gels for 45 min (Soares et al. 2014c). One can conclude that the compromised bond performance of some self-etch adhesives to enamel and dentin creates a more permeable tooth/restoration interface, facilitating H_2O_2 diffusion through the dental structure. The interface of resin-modified glass-ionomer cement (RMGIC) seems to present the same susceptibility to H_2O_2 as self-etch adhesive systems. The shear bond strength of RMGIC to tooth structure is significantly lower than that observed for etch-and-rinse adhesive systems, due to the low cohesive strength of GIC (Marquezan et al. 2011; Bonifácio et al. 2012; Nujella et al. 2012). According to our results, the application of a 35% H_2O_2 gel onto enamel/dentin discs containing RMGIC interfaces subjected to hydrolytic degradation allowed for a more intense H_2O_2 diffusion through hard mineralized dental structures and increased the in vitro cytotoxicity to odontoblast-like cells, leading to increased oxidative stress and IL-1β overexpression, as well as disturbing the expression of odontoblastic markers (Soares et al. 2016b).

Therefore, clinicians should be cautious when selecting the bleaching protocol to be applied in patients that have restored teeth, especially incisors. The materials used for restoring carious and non-carious lesions, as well as the integrity of

restoration margins, should be also analyzed in detail to prevent, at least partially, the damage to pulp tissue and possible post-bleaching pain.

5.6 Strategies to Prevent Tooth Bleaching Mediated Pulp Cell Oxidation

The primary strategy for minimizing pulp tissue damage is based on reducing the amount of residual H_2O_2 capable of reaching the pulp tissue.

As discussed above, reducing the H_2O_2 concentration on bleaching gels, and the contact time of these toxic products with the tooth structure, seems to have a positive biologic effect. According to our results, a 17.5% H_2O_2 bleaching gel reduced the trans-enamel and trans-dentinal toxic effects of the therapy to pulp cells, commonly observed after professional in-office tooth bleaching using 35% H_2O_2 gels (Soares et al. 2014a) (Fig. 5.8a, b). However, even a concentration of 17.5% H_2O_2 decreased the pulp cell viability by 86%, 77%, and 65% after applying the product on enamel/dentin discs for 45, 15, or 5 min, respectively (Soares et al. 2014a).

Regarding the bleaching effectiveness, a similar color alteration was achieved after four sessions when the 17.5% H_2O_2 gel was applied for 45 min on enamel compared to a traditional protocol with 35% H_2O_2 gel. However, the application of this 17.5% H_2O_2 gel for 15 or 5 min on enamel did not result in the same bleaching outcome as that of high concentrations, even after six sessions (Soares et al. 2014b). A more positive biological effect on human dental pulp cells was achieved when less concentrated bleaching gels such as 8 to 10% H_2O_2 were used, but the bleaching effectiveness remained the main drawback for these alternative treatments (Soares et al. 2015a).

Several clinical therapies have been proposed to minimize the adverse effects caused by in-office bleaching therapies widely employed in the last years. Among them are the use of desensitizing agents applied topically or incorporated into the bleaching gels (Donassollo et al. 2021) in addition to the prescription of analgesic or anti-inflammatory drugs (Santana et al. 2019). Even if these medications may reduce the post-bleaching sensitivity, they are palliative alternatives that do not prevent H_2O_2 diffusion through the enamel/dentin and its disastrous damage to the pulp-dentin complex. As already reported above, the use of bleaching gels with low concentrations of H_2O_2 limits the chromatic change of dental tissues, which makes this treatment unfeasible because it requires several clinical sessions to promote a satisfactory esthetic outcome (Ribeiro et al. 2022a). Researchers have also shown that the association of ozone (O_3) and bleaching gels in vivo may enhance the esthetic efficacy and reduce the post-bleaching tooth sensitivity (Al-Omiri et al. 2018). However, there are no laboratorial or clinical trials confirming that such interesting approach is capable of preventing the diffusion of H_2O_2 across enamel/dentin and reducing the intense pulp injury caused by the conventional in-office

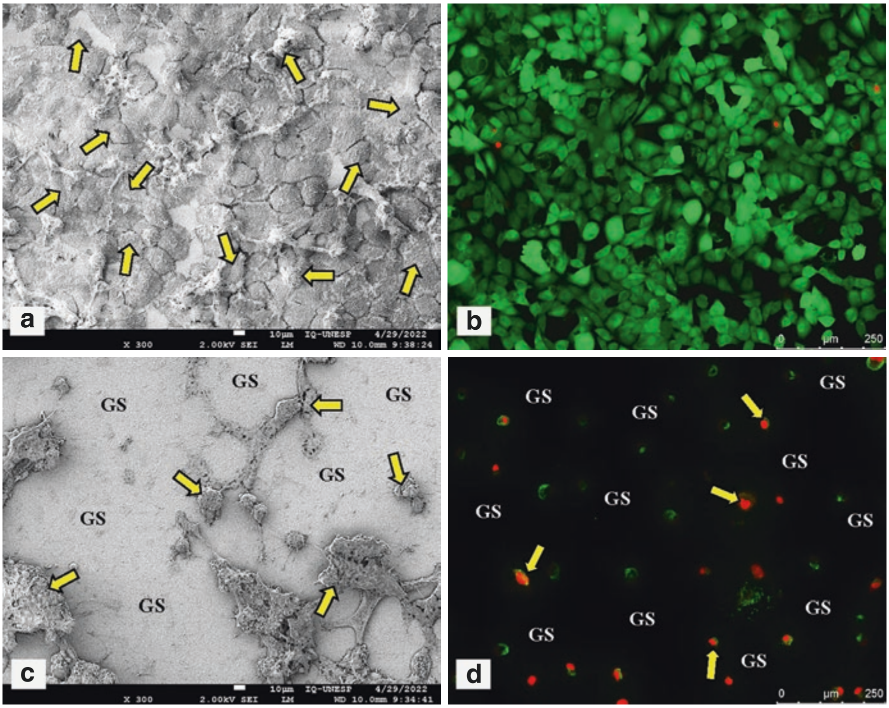

Fig. 5.8 (**a**) MDPC-23 cells were seeded on sterilized glass substrate and placed in incubator at 37 °C and 5% CO_2. After 3 days, a number of normal cells proliferated and remained attached to the substrate (arrows). SEM, original magnification = ×300. (**b**) The Live/Dead assay shows that normal MDPC-23 cells that remained attached to the substrate have positive staining for Calcein AM (green). (**c**) MDPC-23 cells seeded on sterilized glass substrate were exposed to components of a bleaching gel with 35% H_2O_2 that diffused through enamel/dentin. Most of lethally damaged cells detached from the substrate. Note that those few cells that remained attached to the glass substrate exhibit deep morphologic changes (arrows) (GS: glass substrate exposed). SEM, original magnification = ×300. (**d**) Most of those scarce cells spread on the glass substrate have increased positive staining for Ethyl homodimer-1 (red) fluorescence probe, which connects DNA bands of cells with disrupted membrane (arrows)

therapies. Hence, strategies based on increasing the decomposition of H_2O_2 into hydroxyl radicals (OH•) to eliminate residual H_2O_2 that can diffuse deeply into enamel and dentin to reach the pulp tissue in concentrations high enough to cause intense tissue damage and post-bleaching sensitivity have been recently evaluated. In these studies, the authors showed that adding catalyzing agents in bleaching gels of variable H_2O_2 concentrations may result in a similar esthetic efficacy to that obtained with conventional in-office bleaching (Bortolatto et al. 2016; Monterubbianesi et al. 2021). This innovative strategy aims to accelerate the process of H_2O_2 decomposition by the catalyzing agent, which potentiates the production of other highly reactive ROS with an extremely short half-life (Yao et al. 2006). After efficiently and rapidly interacting with the chromophores in dental tissues,

these new ROS are eliminated, decreasing the possibility of damage to pulp cells (Ortecho-Zuta et al. 2019, 2021; Soares et al. 2019).

It is known that $OH^{\bullet}$ has a higher oxidation potential ($E^0 = 2.8$ V) in comparison with H_2O_2 ($E^0 = 1.8$ V), which, in turn, makes its interaction with chromogens more effective. Also, since $OH^{\bullet}$ is considered as a transient molecule (half-life of 10^{-9} s), diffusion of high concentrations of this free radical into the pulp chamber is not expected. Indeed, some researchers have demonstrated that incorporating enzymes or chemical substances containing iron or manganese as active principles in bleaching therapies enhances the esthetic outcome and minimizes H_2O_2 diffusion through enamel and dentin (Torres et al. 2010, 2013; Ribeiro et al. 2022a, b). These molecules accelerate H_2O_2 decomposition into $OH^{\bullet}$ through a catalyst Fenton reaction. Results obtained by our research group demonstrated that incorporating ferrous sulfate to the thickening agent of a 35% H_2O_2 gel reduced in about 15% the harmful effect of the bleaching product on odontoblast-like cells (Duque et al. 2014). We also determined that manganese chloride and hemic peroxidase can reduce the toxicity and oxidative stress on pulp cells mediated by a 35% H_2O_2 bleaching gel (Soares et al. 2019). All these molecules increased the esthetic bleaching effectiveness and decreased the H_2O_2 diffusion through the mineralized tooth structures (Fig. 5.9a, b).

Several studies have shown that increasing the H_2O_2 degradation rate is possible through the association with biopolymers (Ortecho-Zuta et al. 2021, 2022) and, more recently, with violet LED irradiation (Martins et al. 2022). In a current investigation, our research group used polycaprolactone and hydroxypropyl methylcellulose to prepare nanofiber scaffolds (NSc) and a horseradish peroxidase

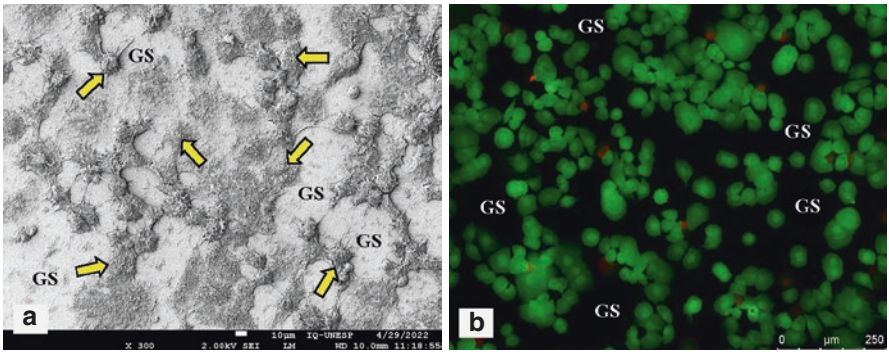

Fig. 5.9 (**a**) MDPC-23 cells seeded on sterilized glass substrate were exposed to components of a manganese oxide-enriched bleaching gel. The higher number of viable cells that remained attached to the substrate in comparison with Fig. 5.8c demonstrates that adding catalyzing agents in bleaching gels may reduce the trans-amelodentinal cytotoxicity frequently caused by the conventional in-office therapy. Note that the morphology of the MDPC-23 cells attached to the substrate (arrows) is similar to that observed in those non-treated cells, which were maintained in normal environment (Fig. 5.8a). SEM, original magnification = ×300. (**b**) The Live/Dead assay shows that almost all MDPC-23 cells that remained attached to the substrate have positive staining for Calcein AM (green), indicating their viability

enzyme-enriched primer catalyst (PrCa), respectively (Ortecho-Zuta et al. 2022). The aim of this study was to assess the esthetic efficacy and toxicity of an in-office bleaching gel with 35% H_2O_2 applied for different time intervals (15 or 30 min) on the enamel previously coated with the polymeric biomaterials. We demonstrated that covering the dental enamel with NSc and PrCa before application of the bleaching gel increases the esthetic efficacy and reduces the time necessary to obtain dental bleaching similar to that achieved by the conventional in-office therapy. Additionally, the reduction in trans-amelodentinal diffusion of H_2O_2, which was observed when the in-office bleaching gel was applied on enamel coated with the polymeric biomaterials, prevented the intense cytotoxicity caused by this professional therapy. This study showed that the association of NSc and PrCa enabled the esthetic efficacy promoted by conventional in-office dental bleaching to be achieved in only 15 min of application of 35% H_2O_2 on enamel, which also significantly reduced the cytotoxicity of this modality of professional therapy.

The use of violet LED (V-LED) for tooth bleaching has been justified by the fact that the specific light wavelength employed in this innovative approach (405–410 nm) corresponds to the absorption peak of chromophores. Therefore, it has been suggested that the V-LED, even without gels, may trigger the instability and rupture of chromophore chemical bonds, promoting the bleaching effect by a photophysical process (Zanin et al. 2016). Despite the limited bleaching effects reached when V-LED is employed alone, the use of this strategy seems to favor the esthetic outcome when the bleaching gel containing H_2O_2 is irradiated (Gallinari et al. 2019; Brugnera et al. 2020; Kury et al. 2020). Taking into consideration that the photocatalysis of H_2O_2 present in the bleaching gels is a new approach actually assessed to improve the professional bleaching therapy, there is still no consensus concerning the best and safe protocols for clinical application. Thus, in a current study, Ribeiro et al. (2022b) evaluated whether increasing the irradiation time of a commercial in-office bleaching gel (35% H_2O_2) with V-LED may favor esthetic efficacy and reduce the trans-amelodentinal cytotoxicity. The authors showed that using V-LED for irradiation of a high concentrated bleaching gels may represent an attractive alternative to improve the rate of color changes in dental tissues. However, increasing V-LED irradiation time neither enhances esthetic efficacy nor reduces the trans-amelodentinal cytotoxicity of in-office tooth bleaching. Martins et al. (2022) demonstrated that the V-LED irradiation of bleaching gels with different concentrations of H_2O_2 (10%, 20%, and 35%) submitted to other strategies of H_2O_2 catalysis may limit the trans-amelodentinal cytotoxicity of in-office tooth bleaching, providing higher safety to this professional esthetic therapy. In this study, the effect of associating nanofiber scaffolds (NSc) and a primer catalyst (PrCa) to improve esthetic efficacy, degradation kinetics, and cytotoxicity of bleaching gels, irradiated or not with V-LED, was assessed. The authors demonstrated that the highest color change and whitening index occurred when a gel with 35% H_2O_2 was applied for 45 min on the enamel previously coated with both biopolymers and then irradiated with V-LED (Fig. 5.10a, b). The most interesting finding of this study was that bleaching gel with 10% H_2O_2 submitted to the same procedure caused the lowest indirect cytotoxic

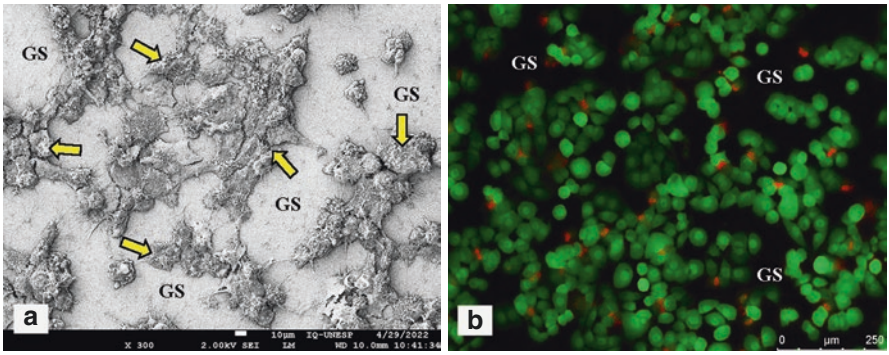

Fig. 5.10 (**a**) MDPC-23 cells seeded on sterilized glass substrate were exposed to components of a bleaching gel applied on enamel covered with biopolymers (NSc and PrCa) and then irradiated with V-LED. The higher number of viable cells (arrows) that remained attached to the substrate in comparison with Fig. 5.8c demonstrates that this innovative strategy may reduce the trans-amelodentinal cytotoxicity caused by the conventional in-office therapy. The MDPC-23 cells, which are organized in epithelioid nodules, exhibit morphology similar to that observed in those non-treated cells (Fig. 5.8a). SEM, original magnification = ×300. (**b**) The Live/Dead assay shows that almost all MDPC-23 cells that remained attached to the substrate have positive staining for Calcein AM (green), indicating their viability

effect, and the color change reached was 24% higher than that obtained for the conventional in-office therapy.

The approach of covering the enamel with biopolymers and then applying the bleaching gel, which is photocatalyzed with V-LED, has been used in a current clinical trial. The preliminary data showed that all patients submitted to this innovative strategy to be used in-office reported no post-bleaching tooth sensitivity. In addition, this strategy applied for only 15 min resulted in esthetic outcome similar to that observed when on session of 45 min of the conventional in-office bleaching therapy was performed. In this way, the chemical activation of high- or low-concentration in-office bleaching gels has driven new perspectives for obtaining effective and biocompatible products and therapies capable of turning this esthetic procedure safer and painless.

The administration of antioxidant agents seems to have a more rational appeal since these agents may act by limiting the extension of oxidative damage by donating an electron to the arriving free radicals (Moores 2013). Previous studies performed by our group demonstrated that antioxidant molecules, such as alpha-tocopherol (vitamin E) and ascorbic acid (vitamin C), could prevent the

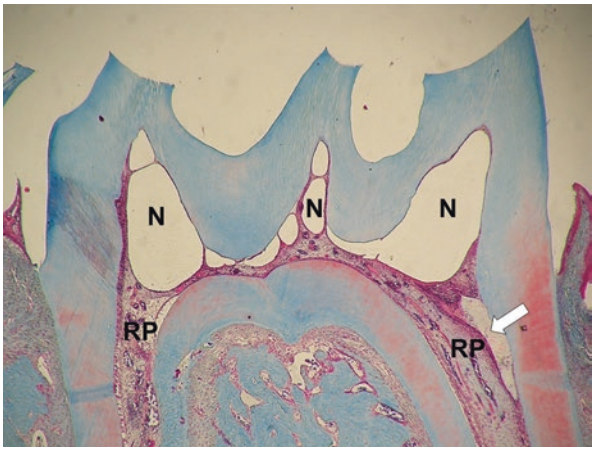

Fig. 5.11 First molar of rat subjected to bleaching treatment. Note the wide necrosis (N) of the coronal pulp tissue. The radicular pulp (RP) is well maintained despite the notable inflammatory reaction and a small local area of edema (arrow). Masson's trichrome, 32×

H_2O_2-mediated pulp cell damage since they inactivate extracellular ROS arising from bleaching gels, and the intracellular ones released by cells undergo oxidative stress (Lima et al. 2010a, b; Vargas et al. 2014a, b). We also observed that oral administration of ascorbic acid (200 mg/Kg) 90 min before applying 35% H_2O_2 bleaching gel for 5 min on rat molars protected the pulp tissue against the toxic effects of this therapy (Lima et al. 2016). All bleached teeth from animals with no ascorbic acid pretreatment featured large necrosis areas on the coronal pulp 6 and 24 h after bleaching (Fig. 5.11).

On the other hand, a smaller necrotic area, mainly located in the upper zone of the pulp horn, was observed in 80% of the animals that received oral administration of ascorbic acid before tooth bleaching. Also, 24 h after bleaching, only 40% of teeth exhibited punctual areas of necrosis associated with discrete disorganization of the reminiscent pulp tissue (Fig. 5.12) (Lima et al. 2016).

Therefore, one can conclude that antioxidant therapy is capable of preventing the strong immediate pulp damage caused by in-office tooth bleaching procedures and enhance pulpal healing with time. However, further laboratory studies and clinical trials are needed to determine the ideal and safe doses of antioxidant agents to be administered to human beings and associate this interesting systemic therapy with different strategies of catalyzing the H_2O_2 present in bleaching gels commonly used in professional tooth bleaching treatments.

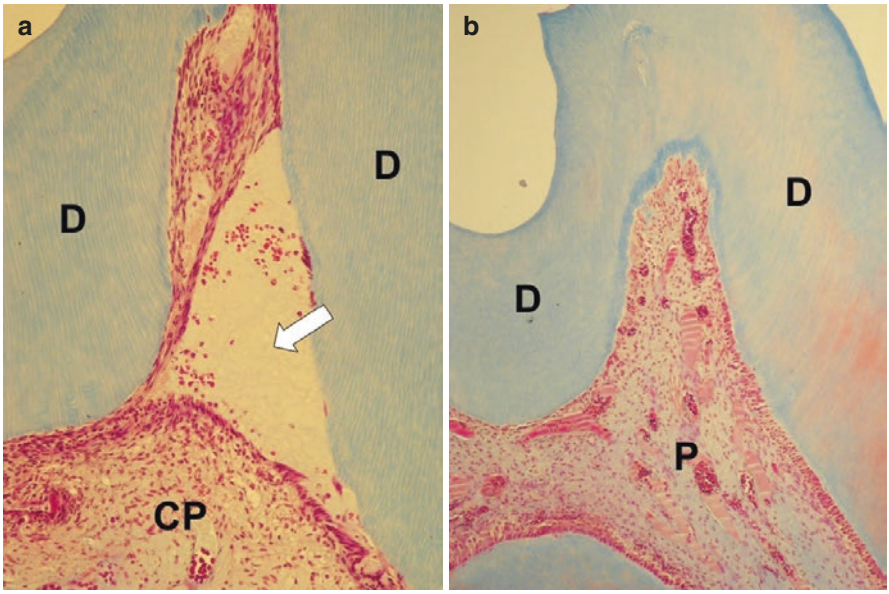

Fig. 5.12 (**a**) Coronal pulp (CP) of a molar of rat that received oral administration of ascorbic acid (200 mg/Kg) 90 min prior to application of bleaching agent. Despite the intense damage in part of the pulp horn (arrow), a large area of the subjacent coronal pulp is preserved. Masson's trichrome, 125×. (**b**) Seven days after tooth bleaching, complete pulpal healing (P) was observed in teeth of rats treated with ascorbic acid. Masson's trichrome, 96× (D = dentin)

References

Almeida LC, Soares DG, Azevedo FA, Gallinari Mde O, de Souza Costa CA, Santos PH, Briso AL (2015) At-home bleaching: color alteration, hydrogen peroxide diffusion and cytotoxicity. Braz Dent J 26:378–383

Al-Omiri MK, Al Nazeh AA, Kielbassa AM et al (2018) Randomized controlled clinical trial on bleaching sensitivity and whitening efficacy of hydrogen peroxide versus combinations of hydrogen peroxide and ozone. Science 8(1):1–10. https://doi.org/10.1038/s41598-018-20878-0

Alongi DJ, Yamaza T, Song Y, Fouad AF, Romberg EE, Shi S, Tuan RS, Huang GT (2010) Stem/progenitor cells from inflamed human dental pulp retain tissue regeneration potential. Regen Med 5:617–631

Benetti AR, Valera MC, Mancini MN, Miranda CB, Balducci I (2004) In vitro penetration of bleaching agents into the pulp chamber. Int Endod J 37:120–124

Benetti F, Gomes-Filho JE, Ferreira LL, Sivieri-Araújo G, Ervolino E, Briso ALF, Cintra LTA (2018) Concentration-dependent effect of bleaching agents on the immunolabelling of interleukin-6, interleukin-17 and CD5-positive cells in the dental pulp. Int Endod J 51(7):789–799

Bonafé E, Bacovis CL, Iensen S, Loguercio AD, Reis A, Kossatz S (2013) Tooth sensitivity and efficacy of in-office bleaching in restored teeth. J Dent 41:363–369

Bonifácio CC, Shimaoka AM, de Andrade AP, Raggio DP, van Amerongen WE, de Carvalho RC (2012) Micro-mechanical bond strength tests for the assessment of the adhesion of GIC to dentine. Acta Odontol Scand 70:555–563

Bortolatto JF, Trevisan TC, Bernardi PS, Fernandez E, Dovigo LN, Loguercio AD, de Oliveira B, Junior O, Pretel H (2016) A novel approach for in-office tooth bleaching with 6% H2O2/TiO_N and LED/laser system-a controlled, triple-blinded, randomized clinical trial. Lasers Med Sci 31:437–444

Boushell LW, Ritter AV, Garland GE, Tiwana KK, Smith LR, Broome A, Leonard RH (2012) Nightguard vital bleaching: side effects and patient satisfaction 10 to 17 years post-treatment. J Esthet Restor Dent 24:211–219

Brugnera AP, Nammour S, Rodrigues JA, Mayer-Santos E, De Freitas PM, Brugnera A, Zanin F (2020) Clinical evaluation of in-office dental bleaching using a violet light-emitted diode. Photobiomodul Photomed Laser Sur 38:98–104

Camargo SEA, Valera MC, Camargo CHR, Mancini MNG, Menezes MM (2007) Penetration of 38% hydrogen peroxide into the pulp chamber in bovine and human teeth submitted to office bleach technique. J Endod 33:1074–1077

Camargo SE, Cardoso PE, Valera MC, de Araújo MA, Kojima AN (2009) Penetration of 35% hydrogen peroxide into the pulp chamber in bovine teeth after LED or Nd:YAG laser activation. Eur J Esthet Dent 4:82–88

Carregosa Santana ML, Leal PC, Reis A, Faria-E-Silva AL (2019) Effect of anti-inflammatory and analgesic drugs for the prevention of bleaching-induced tooth sensitivity: a systematic review and meta-analysis. J Am Dent Assoc 150:818–829

Coldebella CR, Ribeiro AP, Sacono NT, Trindade FZ, Hebling J, de Souza Costa CA (2009) Indirect cytotoxicity of a 35% hydrogen peroxide bleaching gel on cultured odontoblast-like cells. Braz Dent J 20:267–274

Cooper PR, Takahashi Y, Graham LW, Simon S, Imazato S, Smith AJ (2010) Inflammation-regeneration interplay in the dentine-pulp complex. J Dent 38:687–697

Cooper PR, Holder MJ, Smith AJ (2014) Inflammation and regeneration in the dentin-pulp complex: a double-edged sword. J Endod 40:S46–S51

da Silva LMAV, Cintra LTA, de Alcântara S, da Silva Machado NE, Benetti F, Ervolino E, Briso ALF (2022) Influence of violet LED associated or not with peroxide gel on inflammation, mineralization, and collagen fiber maturation in dentin and pulp tissue. Photodiagn Photodyn Ther 39:102959

de Almeida LC, Costa CA, Riehl H, dos Santos PH, Sundfeld RH, Briso AL (2012) Occurrence of sensitivity during at-home and in-office tooth bleaching therapies with or without use of light sources. Acta Odontol Latinoam 25:3–8

de Almeida LC, Soares DG, Gallinari MO, de Souza Costa CA, Dos Santos PH, Briso AL (2015) Color alteration, hydrogen peroxide diffusion, and cytotoxicity caused by in-office bleaching protocols. Clin Oral Investig 19:673–680

de Oliveira Duque CC, Soares DG, Basso FG, Hebling J, de Souza Costa CA (2017) Influence of enamel/dentin thickness on the toxic and esthetic effects of experimental in-office bleaching protocols. Clin Oral Investig 21:2509–2520

de Oliveira Duque CC, Soares DG, Briso ALF, Ortecho-Zuta U, de Oliveira Ribeiro RA, Hebling J, de Souza Costa CA (2020) Influence of tooth pigmentation on H2O2 diffusion and its cytotoxicity after in-office tooth bleaching. Oper Dent 45:632–642

de Oliveira Ribeiro RA, Zuta UO, Soares IPM, Anselmi C, Soares DG, Briso ALF, Hebling J, de Souza Costa CA (2022) Manganese oxide increases bleaching efficacy and reduces the cytotoxicity of a 10% hydrogen peroxide bleaching gel. Clin Oral Investig 26:7277–7286. https://doi.org/10.1007/s00784-022-04688-3

de Paula EA, Nava JA, Rosso C, Benazzi CM, Fernandes KT, Kossatz S, Loguercio AD, Reis A (2015) In-office bleaching with a two- and seven-day intervals between clinical sessions: a randomized clinical trial on tooth sensitivity. J Dent 43:424–429

de Souza Costa CA, Riehl H, Kina JF, Sacono NT, Hebling J (2010) Human pulp responses to in-office tooth bleaching. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 109:e59–e64

Didier VF, Batista AUD, Montenegro RV, Fonseca RB, Carvalho FG, Barros S (2013) Influence of hydrogen peroxide-based bleaching agents on the bond strength of resin–enamel/dentin interfaces. Int J Adhes Adhes 47:141–145

Donassollo SH, Donassollo TA, Coser S, Wilde S, Uehara JLS, Chisini LA, Correa MB, Cenci MS, Demarco FF (2021) Triple-blinded randomized clinical trial comparing efficacy and tooth sensitivity of in-office and at-home bleaching techniques. J Appl Oral Sci 29:e20200794

Dudek M, Roubickova A, Comba L, Housova D, Bradna P (2013) Effect of postoperative peroxide bleaching on the stability of composite to enamel and dentin bonds. Oper Dent 38:394–407

Duque CC, Soares DG, Basso FG, Hebling J, de Souza Costa CA (2014) Bleaching effectiveness, hydrogen peroxide diffusion, and cytotoxicity of a chemically activated bleaching gel. Clin Oral Investig 18:1631–1637

Esteves LMB, Dos Santos PH, Fagundes TC, de Oliveira GM, de Mello Antonaccio GB, Cintra LTA, Briso ALF (2022) Effect of bleaching gel volume on color change and postoperative sensitivity: a randomized clinical study. Clin Oral Investig 26:2527–2536

Gallinari M, Fagundes TFL, Almeida SM, Barboza A, Briso ALF (2019) A new approach for dental bleaching using violet light with or without the use of whitening gel: study of bleaching effectiveness. Oper Dent 44:521–529

Gökay O, Yilmaz F, Akin S, Tunçbìlek M, Ertan R (2000) Penetration of the pulp chamber by bleaching agents in teeth restored with various restorative materials. J Endod 26:92–94

Gökay O, Müjdeci A, Algn E (2004) Peroxide penetration into the pulp from whitening strips. J Endod 30:887–889

Gökay O, Müjdeci A, Algin E (2005) In vitro peroxide penetration into the pulp chamber from newer bleaching products. Int Endod J 38:516–520

He LB, Shao MY, Tan K, Xu X, Li JY (2012) The effects of light on bleaching and tooth sensitivity during in-office vital bleaching: a systematic review and meta-analysis. J Dent 40:644–653

Kury M, Wada EE, Silva DPD, Tabchoury CPM, Giannini M, Cavalli V (2020) Effect of violet LED light on in-office bleaching protocols: a randomized controlled clinical trial. J Appl Oral Sci 28:e20190720

Lee DH, Lim BS, Lee YK, Yang HC (2006) Effects of hydrogen peroxide (H2O2) on alkaline phosphatase activity and matrix mineralization of odontoblast and osteoblast cell lines. Cell Biol Toxicol 22:39–46

Lee YH, Kang YM, Heo MJ, Kim GE, Bhattarai G, Lee NH, Yu MK, Yi HK (2013) The survival role of peroxisome proliferator-activated receptor gamma induces odontoblast differentiation against oxidative stress in human dental pulp cells. J Endod 39:236–241

Lima AF, Lessa FC, Hebling J, de Souza Costa CA, Marchi GM (2010a) Protective effect of sodium ascorbate on MDPC-23 odontoblast-like cells exposed to a bleaching agent. Eur J Dent 4:238–244

Lima AF, Lessa FC, Mancini MN, Hebling J, de Souza Costa CA, Marchi GM (2010b) Transdentinal protective role of sodium ascorbate against the cytopathic effects of H2O2 released from bleaching agents. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 109:e70–e76

Lima AF, Ribeiro AP, Soares DG, Sacono NT, Hebling J, de Souza Costa CA (2013) Toxic effects of daily applications of 10% carbamide peroxide on odontoblast-like MDPC-23 cells. Acta Odontol Scand 71:1319–1325

Lima AF, Marques MR, Hebling J, Marchi GM, Soares DG, de Souza Costa CA (2016) Antioxidant therapy enhances pulpal healing in bleached teeth. Restor Dent Endod 41:44–54

Markowitz K (2010) Pretty painful: why does tooth bleaching hurt? Med Hypotheses 74:835–840

Marquezan M, Skupien JA, da Silveira BL, Ciamponi A (2011) Nanoleakage related to bond strength in RM-GIC and adhesive restorations. Eur Arch Paediatr Dent 12:15–21

Martins BV, Dias MF, de Oliveira Ribeiro RA, Leite MLAES, Hebling J, de Souza Costa CA (2022) Innovative strategy for in-office tooth bleaching using violet LED and biopolymers as H2O2 catalysts. Photodiagn Photodyn Ther 38:102886

Matsui S, Takahashi C, Tsujimoto Y, Matsushima K (2009) Stimulatory effects of low-concentration reactive oxygen species on calcification ability of human dental pulp cells. J Endod 35:67–72

Meireles SS, Santos IS, Bona AD, Demarco FF (2010) A double-blind randomized clinical trial of two carbamide peroxide tooth bleaching agents: 2-year follow-up. J Dent 38:956–963

Min KS, Kwon YY, Lee HJ, Lee SK, Kang KH, Lee SK, Kim EC (2006) Effects of proinflammatory cytokines on the expression of mineralization markers and heme oxygenase-1 in human pulp cells. J Endod 32:39–43

Min KS, Lee HJ, Kim SH, Lee SK, Kim HR, Pae HO (2008) Hydrogen peroxide induces heme oxygenase-1 and dentin sialophosphoprotein mRNA in human pulp cells. J Endod 34:983–989

Monterubbianesi R, Tosco V, Bellezze T, Giuliani G, Özcan M, Putignano A, Orsini G (2021) A comparative evaluation of nanohydroxyapatite-enriched hydrogen peroxide home bleaching system on color, hardness and microstructure of dental enamel. Materials (Basel) 14:3072

Moores J (2013) Vitamin C: a wound healing perspective. Br J Community Nurs Suppl S6:S8–S11

Nujella BP, Choudary MT, Reddy SP, Kumar MK, Gopal T (2012) Comparison of shear bond strength of aesthetic restorative materials. Contemp Clin Dent 3:22–26

Ortecho-Zuta U, de Oliveira Duque CC, Leite ML, Bordini E, Basso FG, Hebling J, de Souza Costa CA, Soares DG (2019) Effects of enzymatic activation of bleaching gels on hydrogen peroxide degradation rates, bleaching effectiveness, and cytotoxicity. Oper Dent 44:414–423

Ortecho-Zuta U, de Oliveira Duque CC, de Oliveira Ribeiro RA, Leite ML, Soares DG, Hebling J, Briso ALF, de Souza Costa CA (2021) Polymeric biomaterials maintained the esthetic efficacy and reduced the cytotoxicity of in-office dental bleaching. J Esthet Rest Dent 33:1139–1149

Ortecho-Zuta U, de Oliveira Duque CC, de Oliveira Ribeiro RA, Leite ML, Soares DG, Hebling J, Briso ALF, de Souza Costa CA (2022) Strategy for reducing cytotoxicity and obtaining esthetic efficacy with 15 min of in-office dental bleaching. Clin Oral Investig 26:4099–4108

Pashley DH (2013) How can sensitive dentine become hypersensitive and can it be reversed? J Dent 41:S49–S55

Paula-Silva FW, Ghosh A, Silva LA, Kapila YL (2009) TNF-alpha promotes an odontoblastic phenotype in dental pulp cells. J Dent Res 88:339–344

Reis A, Dalanhol AP, Cunha TS, Kossatz S, Loguercio AD (2011) Assessment of tooth sensitivity using a desensitizer before light-activated bleaching. Oper Dent 36:12–17

Reis A, Kossatz S, Martins GC, Loguercio AD (2013) Efficacy of and effect on tooth sensitivity of in-office bleaching gel concentrations: a randomized clinical trial. Oper Dent 38:386–393

Ribeiro RAO, de Oliveira Duque CC, Ortecho-Zuta U, Leite ML, Hebling J, Soares DG, de Souza Costa CA (2022a) Influence of manganese oxide on the esthetic efficacy and toxicity caused by conventional in-office tooth bleaching therapy. Oper Dent 47:425–436

Ribeiro RAO, Peruchi V, Fernandes LO, Anselmi C, Soares IPM, Hebling J, de Souza Costa CA (2022b) The influence of violet LED application time on the esthetic efficacy and cytotoxicity of a 35% H_2O_2 bleaching gel. Photodiagn Photodyn Ther 40:103069

Roderjan DA, Stanislawczuk R, Hebling J, de Souza Costa CA, Soares DG, Reis A, Loguercio AD (2014) Histopathological features of dental pulp tissue from bleached mandibular incisors. J Mater Sci Eng B 4:178–185

Roderjan DA, Stanislawczuk R, Hebling J, de Souza Costa CA, Reis A, Loguercio AD (2015) Response of human pulps to different in-office bleaching techniques: preliminary findings. Braz Dent J 26:242–248

Roubickova A, Dudek M, Comba L, Housova D, Bradna P (2013) Effect of postoperative peroxide bleaching on the marginal seal of composite restorations bonded with self-etch adhesives. Oper Dent 38:644–654

Santana MA, Nahsan FP, Oliveira AH, Loguércio AD, Faria-e-Silva AL (2014) Randomized controlled trial of sealed in-office bleaching effectiveness. Braz Dent J 25:207–211

Soares DG, Ribeiro AP, Sacono NT, Coldebella CR, Hebling J, de Souza Costa CA (2011) Transenamel and transdentinal cytotoxicity of carbamide peroxide bleaching gels on odontoblast-like MDPC-23 cells. Int Endod J 44:116–125

Soares DG, Pontes EC, Ribeiro AP, Basso FG, Hebling J, de Souza Costa CA (2013a) Low toxic effects of a whitening strip to cultured pulp cells. Am J Dent 26:283–285

Soares DG, Ribeiro AP, da Silveira VF, Hebling J, de Souza Costa CA (2013b) Efficacy and cytotoxicity of a bleaching gel after short application times on dental enamel. Clin Oral Investig 17:1901–1909

Soares DG, Basso FG, Hebling J, de Souza Costa CA (2014a) Concentrations of and application protocols for hydrogen peroxide bleaching gels: effects on pulp cell viability and whitening efficacy. J Dent 42:185–198

Soares DG, Basso FG, Pontes EC, Garcia Lda F, Hebling J, de Souza Costa CA (2014b) Effective tooth-bleaching protocols capable of reducing H2O2 diffusion through enamel and dentine. J Dent 42:351–358

Soares DG, Pastana JV, de Oliveira Duque CC, Dias Ribeiro AP, Basso FG, Hebling J, de Souza Costa CA (2014c) Influence of adhesive restorations on diffusion of H2O2 released from a bleaching agent and its toxic effects on pulp cells. J Adhes Dent 16:123–128

Soares DG, Basso FG, Hebling J, de Souza Costa CA (2015a) Immediate and late analysis of dental pulp stem cells viability after indirect exposition to alternative in-office bleaching strategies. Clin Oral Investig 19:1013–1020

Soares DG, Gonçalves Basso F, Hebling J, de Souza Costa CA (2015b) Effect of hydrogen-peroxide-mediated oxidative stress on human dental pulp cells. J Dent 43:750–756

Soares DG, Basso FG, Scheffel DS, Hebling J, de Souza Costa CA (2015c) Responses of human dental pulp cells after application of a low-concentration bleaching gel to enamel. Arch Oral Biol 60:1428–1436

Soares DG, Sacono NT, Ribeiro AP, Basso FG, Scheffel DS, Hebling J, de Souza Costa CA (2015d) Responses of dental pulp cells to a less invasive bleaching technique applied to adhesive-restored teeth. J Adhes Dent 17:155–161

Soares DG, Marcomini N, Basso FG, Pansani TN, Hebling J, de Souza Costa CA (2016a) Indirect cytocompatibility of a low-concentration hydrogen peroxide bleaching gel to odontoblast-like cells. Int Endod J 49:26–36

Soares DG, Marcomini N, Basso FG, Pansani TN, Hebling J, de Souza Costa CA (2016b) Influence of restoration type on the cytotoxicity of a 35% hydrogen peroxide bleaching gel. Oper Dent 41:293–304

Soares DG, Marcomini N, Duque CCDO, Bordini EAF, Zuta UO, Basso FG, Hebling J, Costa CADS (2019) Increased whitening efficacy and reduced cytotoxicity are achieved by the chemical activation of a highly concentrated hydrogen peroxide bleaching gel. J Appl Oral Sci 27:e20180453

Soares DG, Sacono NT, Ribeiro APD, Leite ML, Duque CCDO, Gallinari MDO, Pacheco LE, Hebling J, Costa CADS (2022) Pro-inflammatory mediators expression by pulp cells following tooth whitening on restored enamel surface. Braz Dent J 33:83–90

Tay LY, Kose C, Herrera DR, Reis A, Loguercio AD (2012) Long-term efficacy of in-office and at-home bleaching: a 2-year double-blind randomized clinical trial. Am J Dent 25:199–204

Torres CR, Wiegand A, Sener B, Attin T (2010) Influence of chemical activation of a 35% hydrogen peroxide bleaching gel on its penetration and efficacy--in vitro study. J Dent 38:838–846

Torres CR, Souza CS, Borges AB, Huhtala MF, Caneppele TM (2013) Influence of concentration and activation on hydrogen peroxide diffusion through dental tissues in vitro. ScientificWorldJournal 18:193241

Trindade FZ, Ribeiro AP, Sacono NT, Oliveira CF, Lessa FC, Hebling J, de Souza Costa CA (2009) Trans-enamel and trans-dentinal cytotoxic effects of a 35% H2O2 bleaching gel on cultured odontoblast cell lines after consecutive applications. Int Endod J 42:516–524

Ubaldini AL, Baesso ML, Medina Neto A, Sato F, Bento AC, Pascotto RC (2013) Hydrogen peroxide diffusion dynamics in dental tissues. J Dent Res 92:661–665

Van Landuyt KL, Mine A, De Munck J, Jaecques S, Peumans M, Lambrechts P, Van Meerbeek B (2009) Are one-step adhesives easier to use and better performing? Multifactorial assessment of contemporary one-step self-etching adhesives. J Adhes Dent 11:175–190

Vargas FS, Soares DG, Ribeiro AP, Hebling J, de Souza Costa CA (2014a) Protective effect of alpha-tocopherol isomer from vitamin E against the H_2O_2 induced toxicity on dental pulp cells. Biomed Res Int 2014:895049

Vargas FS, Soares DG, Basso FG, Hebling J, de Souza Costa CA (2014b) Dose-response and time-course of a-tocoferol mediating the cytoprotection of dental pulp cells against hydrogen peroxide. Braz Dent J 25:367–371

Yao S, Yuan S, Xu J, Wang Y, Luo J, Hu S (2006) A hydrogen peroxide sensor based on colloidal MnO2/Na-montmorillonite. Appl Clay Sci 33:35–42

Zanin F (2016) Recent advances in dental bleaching with laser and LEDs. Photomed Laser Surg 34:135–136

Zhu T, Lim BS, Park HC, Son KM, Yang HC (2012) Effects of the iron-chelating agent deferoxamine on triethylene glycol dimethacrylate, 2-hydroxylethyl methacrylate, hydrogen peroxide-induced cytotoxicity. J Biomed Mater Res B Appl Biomater 100:197–205

Part II

Evidence Supporting the Clinical Use of Peroxides for Dental Whitening

At-Home Tooth Bleaching: Current Evidence and Clinical Applications

6

Jorge Perdigão and Edson Araujo

Abstract

A whiter dentition has become a concern for many patients and consumers after the introduction of nightguard vital whitening in 1989. This increased awareness has led to a surge in the popularity of dental whitening (or bleaching) worldwide. Current methods for at-home bleaching include materials prescribed by dental professionals and methods and materials used without the involvement of a dental professional. The latter are over-the-counter (OTC) products available in drugstores and advertised in TV commercials and over the Internet. At-home tooth bleaching with a custom-fitted tray has been considered the safest technique if carried out under the supervision of a dental professional. This chapter compares the efficacy of at-home bleaching techniques, including dental professional-supervised at-home bleaching with carbamide peroxide gel in a custom-fitted tray, over-the-counter bleaching, and combined in-office bleaching with at-home bleaching. We also describe the advantages and disadvantages, side effects, and treatment recommendations with different at-home bleaching techniques based on current scientific information. Clinical cases are added to illustrate clinically relevant techniques.

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6.1 Introduction

Research in psychology has described the type of smiles that distinguish a pleasant from an unpleasant experience (Ekman et al. 1988) as our smile is one of the first characteristics that others see about us. Self-satisfaction with tooth color decreases with increasing severity of discoloration (Xiao et al. 2007). In fact, Hendrie and Brewer (2012) reported that the presence of yellowed teeth and/or deviation from normal tooth spacing have negative effects on ratings of attractiveness and that these effects are markedly stronger in females. An independent survey (American Academy of Cosmetic Dentistry 2004) found that 99.7% of adults in the USA believed that a smile is an important social asset. When respondents were asked, "What would you most like to improve about your smile?," the most common response was "whiter and brighter teeth," which reflects the consumers' choice of tooth bleaching as a method to build self-esteem.

In 1989 Haywood and Heymann introduced the *nightguard vital bleaching* technique using a dentist-fabricated custom-fitted "soft plastic nightguard, approximately 2-mm thick (similar to an athletic mouthguard)," filled with Proxigel (Reed & Carnrick Pharmaceuticals, Kenilworth, NJ, USA). Proxigel was a 10% carbamide peroxide gel available over the counter as a Food and Drug Administration (FDA)-approved antiseptic (Haywood and Heymann 1989). The teeth were treated for 2–6 weeks and evaluated at 2 and 5 weeks to assess color change. This at-home bleaching technique with carbamide peroxide in a custom-fitted tray prescribed by a dental professional is commonly referred to as "at-home whitening," "at-home bleaching," or "tray whitening." [1] It has become very popular worldwide. Although the original technique included 10% carbamide peroxide gel, hydrogen peroxide gel is also used currently for tray whitening. Carbamide peroxide is a precursor of hydrogen peroxide.

6.2 Current At-Home Bleaching Techniques

There are currently several bleaching methods that involve at-home treatment:

(a) At-home bleaching: Carbamide peroxide or hydrogen peroxide gel in a custom-fitted tray prescribed by a dental professional (Fig. 6.1).
(b) Jump-start or combination technique: In-office bleaching with hydrogen peroxide is performed first by a dental professional to provide an initial jump-start bleaching effect. The patient is then prescribed at-home whitening (Kugel et al. 1997), usually 10–20% carbamide peroxide gel for daily application in a custom-fitted tray, which is to be used until the desired shade is obtained (Deliperi et al. 2004).
(c) OTC products for at-home bleaching without professional supervision, such as gels, emulsions, rinses, paint-on films, toothpastes, strips (Fig. 6.2), and kits

[1] The terms "whitening" and "bleaching" are used interchangeably in the literature.

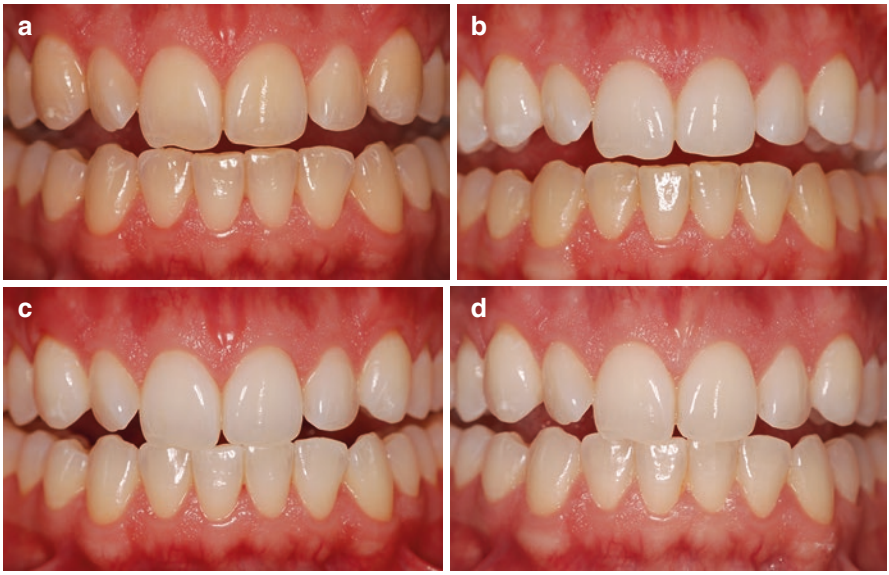

Fig. 6.1 (**a**) Pre-treatment frontal view of a 31-year-old patient who bleached her teeth with 10% carbamide peroxide gel (Opalescence 10%, Ultradent Products) in a custom-fitted tray. (**b**) After 3 weeks of overnight bleaching of the maxillary teeth. (**c**) After bleaching the mandibular teeth for 3 weeks. (**d**) The patient was still happy with the treatment outcome after 1 year

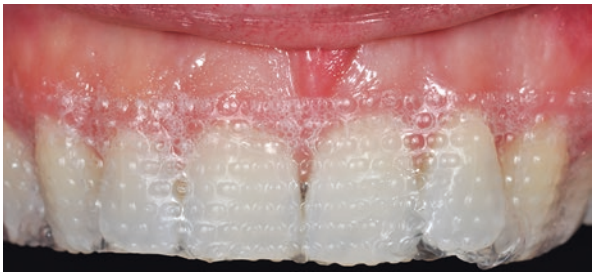

Fig. 6.2 Frontal view of a 38-year-old patient 5 min after inserting a bleaching strip with hydrogen peroxide on her maxillary front teeth

with prefabricated "boil and bite" trays (also known as thermoforming or thermofitting trays) that can be molded in hot water at home by the user (please refer to Chaps. 1 and 4 for more information on OTC whitening products).

The technique known as "waiting-room bleaching" is also carried out using a dentist-prescribed custom-fitted tray. However, this is not considered an at-home bleaching technique because the patient wears the tray filled with 35%–45% carbamide peroxide gel for periods of 15–30 min while waiting in the dental office (Opalescence Patients Instructions 2018).

6.3 At-Home Bleaching with a Custom-Fitted Tray Prescribed by a Dental Professional

6.3.1 Indications

- Intrinsic discolorations:
  - Physiological discoloration caused by aging (Fig. 6.3), which is discussed in Sect. 6.3.9.1 "Physiological Discoloration."
  - Chromogens present in the enamel.
  - Use of antibiotics by the mother during pregnancy or by the patient at the time when permanent teeth are developing. Staining from tetracyclines, especially degrees I and II (Jordan and Boksman 1984) (Fig. 6.4), is discussed in Sect. 6.3.9.2 "Tetracycline-stained teeth."
  - Yellow/brown stains and structural changes from enamel fluorosis (Fig. 6.5), amelogenesis imperfecta, or from idiopathic causes. Staining caused by fluorosis is discussed in more detail in Sect. 6.3.9.3 "Teeth Stained From Enamel Fluorosis." Clinical solutions related to this topic can be found in Part IV of this book.
- Extrinsic discolorations include those caused by chromogenic foodstuff, coffee, tea, and tobacco. Most of these stains can be easily oxidized with peroxides.
- Discolored single tooth caused by calcific metamorphosis (Fig. 6.6), which is discussed in more detail in Sect. 6.3.9.4 "Single-Tooth Darkening From Calcific Metamorphosis of the Pulp."
- Discolored root-filled teeth can be successfully bleached using carbamide peroxide gel (Fig. 6.7). These teeth do not always respond to external tray whitening as well as vital teeth do. The prognosis of the at-home treatment in these cases depends on the nature and duration of the discoloration.
- Anterior teeth prior to esthetic rehabilitation with direct or indirect veneers.

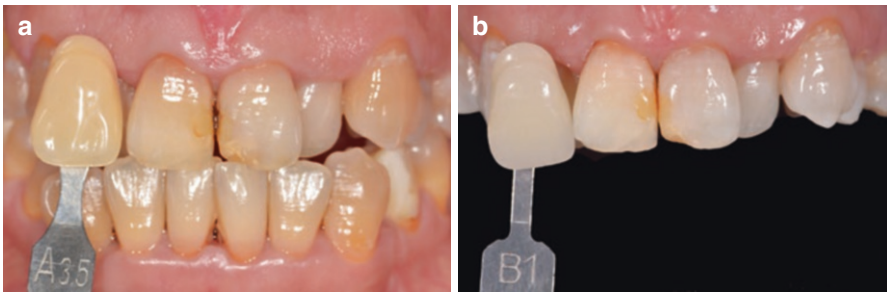

Fig. 6.3 (**a**) Pre-treatment frontal view of a 60-year-old patient who wanted to get his teeth lighter. Patient was informed that the old restorations would need to be replaced after the treatment. (**b**) After 4 weeks of at-home whitening with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride in a custom-fitted tray (Opalescence 10% PF, Ultradent Products)

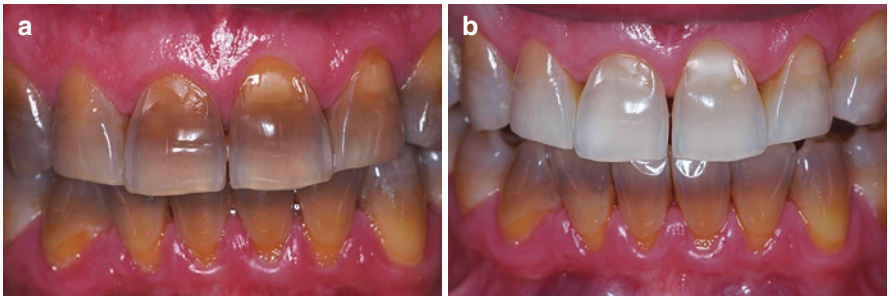

Fig. 6.4 (**a**) A 39-year-old patient who visited the University of Minnesota School of Dentistry for treatment. Patient had a history of tetracycline ingestion during infancy. Patient was informed that clinical studies showed that long-term whitening (2–6 months) might lighten the teeth. However, there was no assurance given of the final whitening result. Patient agreed to proceed with the treatment by wearing a custom-fitted tray with 10% carbamide peroxide gel (Opalescence 10%, Ultradent Products) every night. Instructions were given to the patient, and a new appointment setup for within one month (and every month thereafter). (**b**) After 6 months of 10% carbamide peroxide gel overnight. No sensitivity was reported at any recall period; no alterations of soft tissues were observed. Patient started whitening the lower arch immediately after the completion of the treatment in the upper arch. *Reprinted with Permission from Perdigao J (2010) Dental whitening - revisiting the myths. Northwest Dent 89:19–21, 23–6. (Northwest Dentistry, The Journal of the Minnesota Dental Association)*

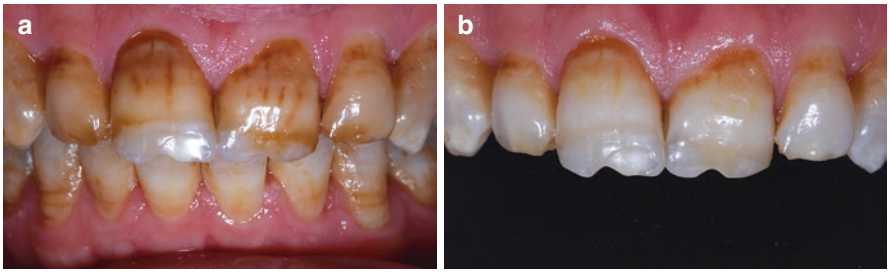

Fig. 6.5 (**a**) This 38-year-old patient was born and raised in an "area where everybody had brown teeth." The patient used to drink water from a water well as a child. The medical history revealed no significant findings. After an intraoral exam, the patient was informed that at-home whitening might improve the appearance of the teeth but that the treatment could span over a few months. Patient agreed to have the teeth bleached with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) at-home in a custom-fitted tray. Patient was scheduled for monthly recalls. (**b**) The appearance of the teeth had improved considerably after 3 months of treatment. Patient was very happy with the current aspect, despite confessing that compliance had not been as per our instructions. Patient chose to stop the treatment for a few months and then restart. *Reprinted with Permission from Perdigao J (2010) Dental whitening - revisiting the myths. Northwest Dent 89:19–21, 23–6. (Northwest Dentistry, The Journal of the Minnesota Dental Association)*

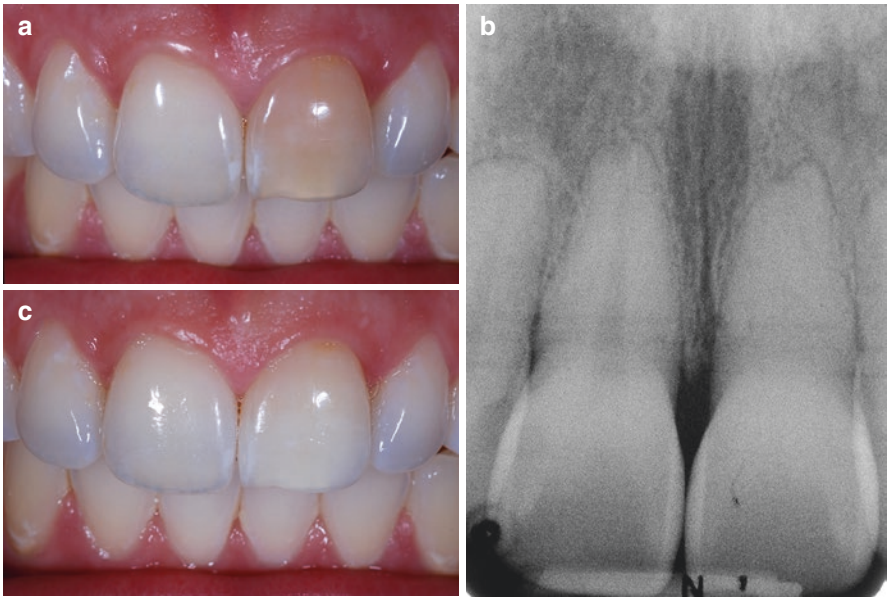

Fig. 6.6 (**a**) Frontal view of maxillary incisors in a 26-year-old patient whose chief complaint was a "dark front tooth" (tooth #9, FDI 2.1). Patient had had a traumatic injury to this tooth at the age of 12 years old. No other signs or symptoms were associated with this tooth. Response to percussion was identical in all maxillary anterior teeth. Although the response to cold was negative, the pulp responded to the electric pulp tester. (**b**) Periapical radiograph showing a calcified pulp space. (**c**) Aspect after 2 weeks of at-home whitening with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray. Patient decided to bleach for another period of two weeks but did not return for the recall appointment

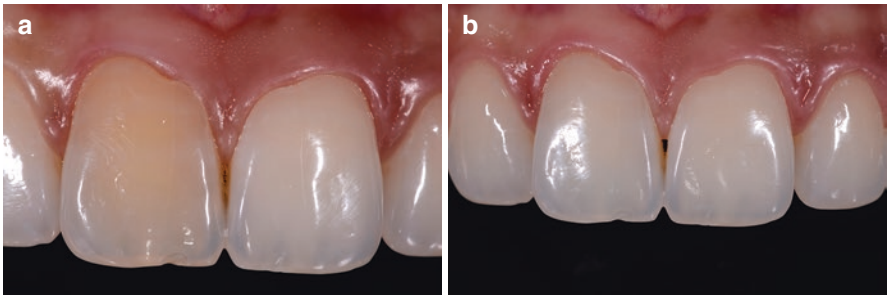

Fig. 6.7 (**a**) A 24-year-old patient had a traumatic injury to tooth #8 (FDI 1.1). After four years the tooth became darker without any symptoms. The patient immediately visited the family dentist who diagnosed pulpal necrosis. Root canal therapy was performed. (**b**) After 5 days of at-home whitening with 22% carbamide peroxide gel (Whiteness Perfect 22%, FGM, Joinville, SC, Brazil) for 2 h twice daily

6.3.2 Contraindications

- Patients' unrealistic expectations.
- Patients unable to carry out the treatment daily. Other bleaching modalities may be better suited for these patients.
- Smoking: We suggest that patients refrain from smoking between 2 h before inserting the tray and 2 h after removing the tray as a precautionary measure. This relative contraindication derives from the findings of the *hamster study* (Weitzman et al. 1986). Despite the findings of the hamster study, it has been reported that at-home bleaching does not induce DNA damage to the gingival tissue of smokers during a 3-week treatment (de Geus et al. 2015c). Smokers showed slightly darker teeth than nonsmokers after 1 month of at-home bleaching treatment, which may be relevant information to disclose to patients prior to starting the bleaching treatment (de Geus et al. 2015a). A clinical study with smokers also concluded that bleaching with 10% carbamide peroxide for 3 h daily for 3 weeks is effective and stable even after 1 year, but dental prophylaxis may be necessary to remove extrinsic stains caused by diet and smoking (de Geus et al. 2015b).
- Pregnancy and breastfeeding: There is not enough available evidence concerning the teratogenicity and the safety of the ingredients of whitening agents for breastfeeding children.
- Root (dentin) hypersensitivity: Preexisting tooth sensitivity must be treated prior to bleaching.
- Gingival recession with discolored roots, especially in elderly patients. Radicular dentin does not respond to whitening as well as coronal dentin (Haywood 2003).
- Possible allergy to inactive components of the bleaching gel. Macrophages produce hydrogen peroxide in our body to help kill bacteria and viruses, therefore the active component hydrogen peroxide is not considered an allergen.
- Acatalasemia, a hereditary disorder in which the blood catalase activity level is below normal (European Commission Scientific Committee on Consumer Products 2007). Catalases are essential enzymes that prevent cell oxidative damage by degrading residual hydrogen peroxide into water and oxygen to protect from too much oxidative activity (Rotstein 1993; Alfonso-Prieto et al. 2009).
- Glucose-6-phosphate dehydrogenase (G6PD) enzyme deficiency is a genetic disorder of erythrocytes which lack the enzyme. G6PD is critical to protecting erythrocytes against oxidative stress. Its deficiency may lead to hemolysis in the presence of certain environmental factors such as infection and some medications and foods, causing the erythrocytes to destroy prematurely and preventing patient with this disorder to break down hydrogen peroxide (European Commission Scientific Committee on Consumer Products 2007; Harcke et al. 2019).
- Xerostomia: Dry mouth may affect the degradation of hydrogen peroxide (European Commission Scientific Committee on Consumer Products 2007).
- Deep white spot lesions: Enamel white spot lesions may be better camouflaged with other treatment modalities, including microabrasion and resin infiltration

(Part III of this book), or removal of the discolored area and restoration with a dental adhesive and a resin-based composite material (Part IV of this book).

6.3.3 Advantages

The major advantages of at-home bleaching are its efficacy and posttreatment color stability (Fig. 6.1; Table 6.1) (Swift Jr et al. 1999; Ritter et al. 2002). After 10 years, 43% of patients that bleached their teeth with 10% carbamide peroxide for 6 weeks deemed the color to be stable (Ritter et al. 2002).

6.3.4 Disadvantages

Patient's compliance remains an issue (Table 6.1) because the dental professional is unable to monitor the daily treatment. Meireles et al. (2008a) asked subjects to return all used and unused bleaching gel syringes to ensure compliance based on the amount of gel used. This method, however, is difficult to implement on a regular basis.

Another disadvantage is the longer treatment time of at-home bleaching compared to that of in-office bleaching. However, one session of in-office whitening may not be sufficient to achieve optimal results (Al Shethri et al. 2003).

6.3.5 Efficacy and Durability

Dentist-prescribed overnight bleaching with carbamide peroxide in a custom-fitted tray has been shown to be the safest, most effective method of tooth whitening (Haywood 2003; Matis 2004; Matis et al. 2009a). Numerous clinical studies and reports have described the effectiveness and safety of tray whitening (Reinhardt et al. 1993; Kihn et al. 2000; Cibirka et al. 1999; Matis et al. 1998, 2006; Meireles et al. 2008b; Li 2000; ADA Council on Scientific Affairs 2010, 2012; Carey 2014). According to the American Dental Association Council on Scientific Affairs (2010), "data accumulated over the last 20 years indicate no significant, long-term oral or

Table 6.1 Advantages and disadvantages of at-home whitening with a custom-fitted tray supervised by a dental professional

Advantages	Disadvantages
Very effective and durable whitening	Tooth sensitivity
Backed with clinical and laboratory research	Patient compliance
Safe	Relatively long treatment time
Low cost compared to in-office procedures	Over-the-counter whitening methods are less expensive

systemic health risks associated with professional at-home tooth bleaching materials containing 10% carbamide peroxide."

Two clinical studies evaluated the 2-year efficacy of tray whitening with carbamide peroxide (Swift et al. 1999; Meireles et al. 2010). In the first study, 29 patients had their maxillary teeth treated with a 10% carbamide peroxide gel nightly for 2 weeks. The teeth became eight shades lighter after two weeks. Color was measured with the Vita Classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) organized by value (lighter to darker). Twenty-four patients were recalled after 2 years. The teeth in 20 patients (83.3%) had darkened an average of 2 shades during the first 6 weeks posttreatment. The bleaching effect remained statistically significant at 2 years. Overall patients were satisfied with the shade. In the second study, 92 patients bleached their maxillary anterior teeth with 10% carbamide peroxide or with 16% carbamide peroxide in a custom-fitted tray for 2 h/day over 3 weeks. Shade evaluations were carried out at baseline, 1 month, 6 months (Meireles et al. 2008b), 1 year (Meireles et al. 2009), and 2 years after bleaching (Meireles et al. 2010). Although the 16% carbamide peroxide group showed some reversal of the whitening effect at 1 year (Meireles et al. 2009), both treatment groups had the same median tooth shade 1 year after bleaching, which was still lighter than at baseline. Tooth shade remained lighter than at baseline after 2 years for both carbamide peroxide concentrations tested (Meireles et al. 2010).

Boushell et al. (2012) evaluated patients' satisfaction and reported no side effects of at-home bleaching with 10% carbamide peroxide in a custom-fitted tray up to 17 years posttreatment. Thirty-one participants who had completed the study using 10% carbamide peroxide were contacted at least 10 years posttreatment. Patient satisfaction with tray whitening lasted an average of 12.3 years posttreatment.

For patients that perceive a color regression, dental professionals may recommend a short color touch-up. The original bleaching tray may be loaded with 10% carbamide peroxide gel for 2–3 nights. In case the custom tray no longer fits the patient's teeth because of new restorations or extracted teeth, disposable trays prefilled trays with 10% or 15% hydrogen peroxide gel with potassium nitrate and sodium fluoride (Opalescence Go, Ultradent Products, South Jordan, UT, USA) may be used for 2–3 days. The respective manufacturer recommends decreasing contact times with increasing hydrogen peroxide concentration. For the 10% concentration, the manufacturer suggests 30–60 min daily, whereas for 15% hydrogen peroxide the recommendation is a contact time of 15–20 min daily (Opalescence Go Whitening Features 2022).

Patients often inquire whether they need to refrain from a potentially staining diet during and after at-home whitening. Current evidence from controlled clinical trials suggests that coffee and red wine do not interfere with the outcome of whitening nor do they affect tooth sensitivity (Rezende et al. 2013; Menezes et al. 2021). Peroxide-based whitening agents are effective in preventing any staining from coffee or red wine during the treatment (Cortes et al. 2013). As a result, the recommendation for a nonstaining diet during the bleaching treatment has been challenged. A study determined whether a "white diet" is necessary by evaluating the effects of

coffee, tea, wine, and dark fruits on tooth whitening during the bleaching process (Matis et al. 2015). After analyzing the data from five published studies, the authors concluded that a potentially staining diet was not significantly associated with less tooth whitening, and there was only a weak positive association between tooth whitening and diet for subjects who consumed large amounts of coffee/tea.

Both coffee and red wine cause enamel color change. Red wine, however, stains enamel more intensely than coffee after the whitening regimen is completed (Cortes et al. 2013).

There are several variables that influence the treatment outcome and the associated tooth sensitivity (please refer to Chap. 5), including the technique, the type of bleaching agent, the concentration, and the contact time (Joiner 2006; Buchalla and Attin 2007; Meireles et al. 2008b; Matis et al. 2009a).

6.3.6 Treatment Plan

The correct diagnosis of the origin of the discoloration is critical because different treatment options result in different clinical outcomes. It is, therefore, imperative that the dental professional understands the etiology of a specific tooth discoloration to be able to diagnose and prescribe the proper treatment for each patient.

A full-mouth exam and recent periapical radiographs of the teeth to be bleached are essential during the diagnostic appointment. Intraoral photographs are extremely valuable to document the pretreatment tooth color to include in the patient's record for future comparisons. Pulp testing is always necessary for single-tooth discolorations. Patients must be informed that existing anterior esthetic restorations, including porcelain and composite resins, will not lighten with bleaching agents except for superficial extrinsic stains (Fig. 6.8). *These restorations may need to be replaced after the whitening treatment is completed to ensure an acceptable esthetic outcome.* Additionally, patients must be informed that amalgam restorations in contact

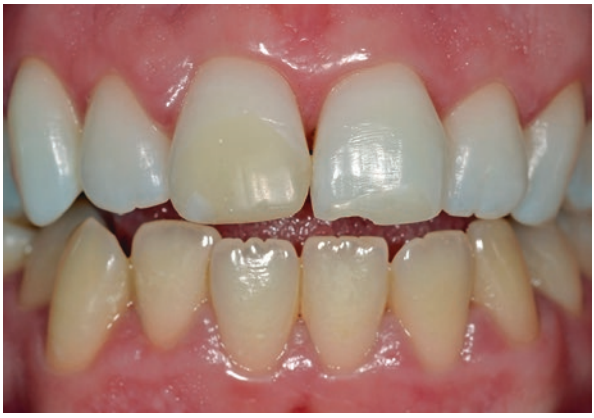

Fig. 6.8 Existing resin-based composite restorations on teeth #8 (FDI 1.1) and #9 (FDI 2.1) after at-home whitening of the maxillary arch with 10% carbamide peroxide with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray for 3 weeks

with the bleaching gel may generate a "greening effect" of the tooth structure in areas immediately adjacent to the amalgam material (Haywood 2002).

Haywood (2003) suggested that wearing a tray on only one arch might improve patients' compliance, as patients can directly observe the color change in one arch compared to the arch that is not undergoing treatment. Additionally, the interocclusal thickness of both maxillary and mandibular trays may exacerbate TMJ disorder symptoms (Robinson and Haywood 2000).

6.3.7 Bleaching Gels

Carbamide peroxide in concentrations between 10% and 22% [2] and hydrogen peroxide in concentrations from 4% to 8% have been used for at-home tray bleaching for different periods of time (Joiner 2006; Meireles et al. 2008b; Matis et al. 2009a). A systematic review and meta-analysis of at-home whitening concluded that carbamide peroxide results in a slightly better whitening efficacy than hydrogen peroxide when applied in a custom-fitted tray (Luque-Martinez et al. 2016).

The bleaching agent for at-home application that has been more frequently scrutinized in the dental literature is 10% carbamide peroxide. Carbamide peroxide is a crystalline material containing a molecule of urea complexed with a single molecule of hydrogen peroxide. As a result of this reaction 10% carbamide peroxide contains approximately 3.3%–3.5% hydrogen peroxide (Cooper et al. 1992; Sulieman 2008; ADA Council on Scientific Affairs 2010). Carbamide peroxide is preferred over hydrogen peroxide because it is more stable than hydrogen peroxide, providing a nonaqueous formula of available hydrogen peroxide (Fischer 1995).

Current carbamide peroxide bleaching gels contain glycerin as a humectant and flavor enhancer; and a thickener, usually a polymer (Carbopol, [3] The Lubrizol Corporation). Carbopol polymers are cross-linked high-molecular-weight homo- and copolymers of acrylic acid, which means that they contain active carboxyl groups making them slightly acidic. To counteract the low pH, bases such as sodium hydroxide may be used to make the bleaching gel less acidic. Similar thickeners and bases are also used in the composition of hydrogen peroxide-containing OTC whitening strips.

6.3.8 Bleaching Tray Design

Several brands of thermoplastic materials are available to fabricate bleaching trays. We use a 0.035″-thick ethylene vinyl acetate (EVA) material that is heated prior to

[2] The chance of a mismatch between the advertised concentration and the actual concentration is very high (Matis et al. 2013).

[3] Carbomer 934P or Carbopol 934P (The Lubrizol Corporation) is primarily used in commercially available oral formulations, including bleaching gels for tray whitening.

forming the tray around the stone model in a vacuum or pressure device. The tray is trimmed in a horseshoe shape (Fig. 6.9) after cooling-off. The final tray design includes trimming the tray to follow the free gingival margin (Haywood 1997b). The design has evolved to a scalloped tray slightly short of the free gingival margin (0.5–1.0 mm) to prevent possible irritation caused by the contact of the bleaching gel with the soft tissues (Chap. 4). A recent clinical trial compared the gingival irritation caused by scalloped vs. non-scalloped bleaching trays with 10% hydrogen peroxide gel. Authors reported a similar outcome; however, the contact time was only 30 min (Carneiro et al. 2022).

The scalloped design is contraindicated with low-viscosity bleaching gels, as the gel is more likely to seep to the mouth and irritate the tongue and lips (Haywood 2003). In specific situations, such as in one-tooth bleaching clinical cases, the tray may be slightly extended gingivally.

In case of inadvertent fabrication of shortened trays, successful whitening still occurs beyond the borders of the short tray without demarcation lines on the teeth (Oliver and Haywood 1999) as peroxides diffuse easily through enamel.

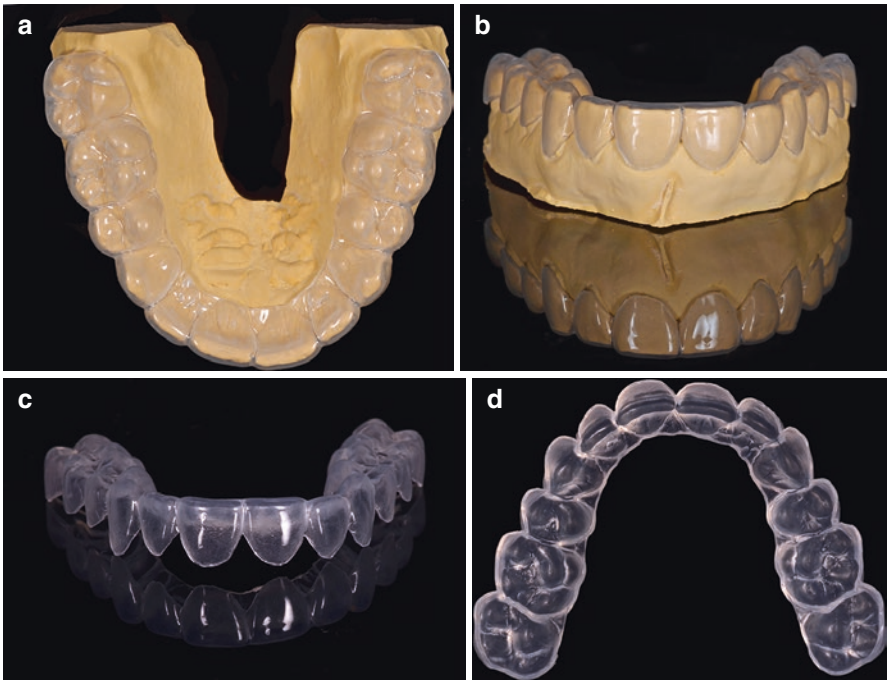

Fig. 6.9 Custom-made bleaching tray for at-home whitening (courtesy of Dr. George Gomes). (**a**) Occlusal view of the tray inserted onto the stone model. The model had been trimmed to remove the palatal aspect and obtain a tighter adaptation of the tray to the teeth. (**b**) Frontal view of the model after the tray was scalloped around the gingival margins. (**c**) Frontal view of the scalloped tray. (**d**) Inside view of the scalloped tray

The use of tray reservoirs to make space to retain the bleaching gel has been patented (Fischer 1992). It remains, nevertheless, a controversial issue. Light-cured block-out resin spacers are recommended by some manufacturers, but the use of spacers to create reservoirs for the bleaching gel does not seem to improve the success of home bleaching (Javaheri and Janis 2000; Matis 2003; Martini et al. 2021). There was no significant color difference at 1 year after bleaching with 10% carbamide peroxide gel without or without reservoirs (Martini et al. 2021). The bleaching gel remains active for longer periods when reservoirs are used (Matis et al. 2002), which may be the reason why tray reservoirs result in higher rates and higher intensity of gingival inflammation during at-home bleaching (Kirsten et al. 2009).

The tray is tried-in after trimming to check for a tight fit making sure that the patient does not feel any sharp edges. The dental professional must examine the soft tissues very carefully at this stage to identify areas of compression that may cause traumatic injury. It is crucial to demonstrate how to dispense the right amount of gel into the tray, usually one drop. To verify that the right amount of gel has been dispensed to cover the buccal aspect of the tooth, the patient is instructed to ensure that a very slight amount of gel has extruded from the tray at its gingival border. Then, the excess gel is wiped out with a toothbrush or a cotton swab to prevent the contact of the gel with the mucosa. The bleaching gel may also be applied from the lingual in case the buccal enamel is covered with restorative material (Fig. 6.10). Haywood and Parker (1999) described a case of porcelain veneers bonded to tetracycline-stained teeth that resulted in a graying of the veneers. A custom-fitted tray with no reservoirs and no gingival scalloping was used to bleach the teeth with 10% carbamide peroxide applied nightly for 9 months from the lingual/palatal aspect.

- The use of reservoirs for the bleaching gel in the tray does not increase the success of home bleaching.
- The use of reservoirs may result in a higher intensity of gingival inflammation.
- The bleaching gel remains active for longer periods of time when reservoirs are used.

6.3.9 Treatment Regimen

6.3.9.1 Physiological Discoloration

The tooth color changes as people age, becoming darker and more yellow (Vaidya et al. 2015; Hassel et al. 2017). The ongoing deposition of secondary dentin within the walls of the pulp chamber is thought to be responsible for the color changes. Clinically relevant changes in tooth color occur within 10 years after the age of 50 (Hassel et al. 2017).

The recommended duration of the treatment for the *original* nightguard vital whitening technique with 10% carbamide peroxide was 2–6 weeks (Haywood and

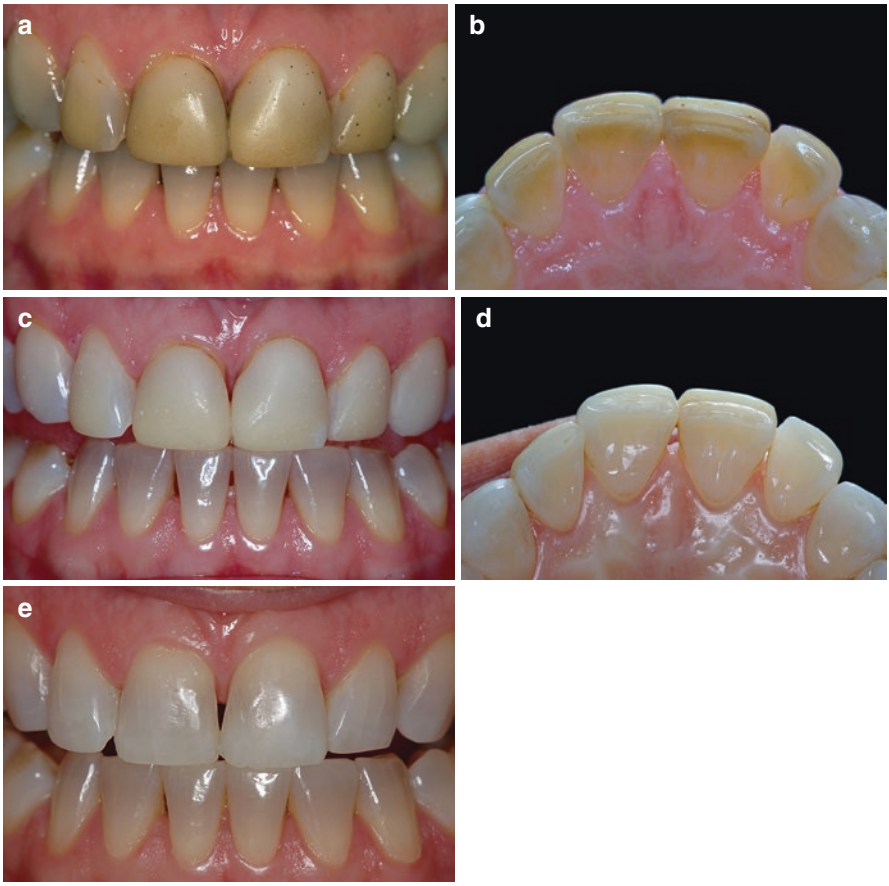

Fig. 6.10 (**a**) A 43-year-old patient visited the University of Minnesota School of Dentistry Comprehensive Care Clinic to ask for a second opinion about having the six anterior maxillary teeth treated with porcelain veneers. The teeth had been restored with direct resin-based composite veneers approximately 20 years back, but the restorative material had become discolored with "black spots all over." (**b**) The lingual view of the maxillary incisors depicted a slight grayish dentin discoloration. Although the medical history was negative for antibiotic ingestion the patient vaguely recalled having some fever episodes and possibly taking antibiotics during childhood. We then informed the patient that we might be able to whiten the teeth if the patient agreed to wear a tray with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) for 2–6 months at night. After the patient agreed and signed the respective consent form, a custom-fitted tray was fabricated, and the patient instructed to apply the whitening gel into the lingual (palatal) aspect of the tray to bleach the teeth from the lingual surface. Patient was also instructed to return to the clinic every month. (**c**) Retracted frontal view after 3 months of at-home whitening. Note that the stains were removed by the peroxide oxidative action. Patient did not experience any sensitivity or any alterations of the soft tissues at each periodical recall. (**d**) Lingual view after 3 months. Compare the dentin shade with that of Fig. 6.10b. Old composite restorations were removed at a subsequent appointment and enamel polished with diamond pastes. (**e**) After observing the result, the patient decided that no other treatment was needed. *Reprinted with Permission from Perdigao J (2010) Dental whitening - revisiting the myths. Northwest Dent 89:19–21, 23–6. (Northwest Dentistry, The Journal of the Minnesota Dental Association)*

Heymann 1989). The typical treatment time for the teeth that are inherently discolored by aging or discolored by diet and chromogenic foodstuff currently ranges from 2 to 4 weeks especially if the treatment is carried out overnight.

Although higher concentrations of peroxides result in a faster rate of whitening than 10% carbamide peroxide, they reach a similar outcome (Matis et al. 2000; Meireles et al. 2009; Basting et al. 2012). Higher concentrations, however, increase the incidence of tooth sensitivity (Matis et al. 2000; Chap. 5). We have not prescribed concentrations above 10% carbamide peroxide for at-home whitening in the last 16 years. The concentration of 10% is the only one that has been approved by the American Dental Association (ADA Seal Product Category 2015).

A clinical study tested four different application times of 10% carbamide peroxide – 15 min, 30 min, 1 h, or 8 h. After 16 days, 15 out of 15 (100%) subjects that had bleached for 8 h/day were satisfied with the results, while only 5/15 subjects that had bleached 1 h per day were satisfied with the results (Cardoso et al. 2010). Matis et al. (2009a) pooled data from nine clinical studies from the same research center, which included in-office and tray whitening. These authors concluded (1) that whitening is most effective when bleaching gel is placed in trays and the trays are used overnight and (2) that tray whitening during the daytime for shorter periods of time was the second most effective whitening method.

- Clinical evidence suggests that 10% carbamide peroxide is as effective as higher concentrations but results in a lower incidence of sensitivity than higher concentrations.
- Overnight tray whitening with 10% carbamide peroxide results in whiter teeth and more durable results than whitening for a few hours during the day.

The recommended treatment regimen of 2–4 weeks is usually adequate for shades A and B (reddish/brownish and reddish/yellowish, respectively) in the Vita Classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter GmbH & Co. KG). When the tooth color has a gray component (C and D shades, Vita Classical A1–D4 shade guide), or when the teeth are discolored by the accumulation of tetracycline stains in dentin, bleaching is more challenging as the stain is more intense around the cervical third.

The prescription of at-home bleaching treatments to child and teenage patients has become a pertinent issue, as parents often ask their family dentists about the possibility of whitening young patients' teeth. Croll (1994) described a protocol for "at-home" tooth bleaching in young patients. According to Croll and Donly (2014), tray whitening of the permanent dentition in children and teenagers is safe and can be performed in a similar manner as for adults. A manufacturer of whitening products has also claimed that the ideal age to whiten the teeth is about 14 (Kör Whitening 2022b). The American Academy of Pediatric Dentistry has published a policy since 2009 on the use of dental bleaching for child and adolescent patients (American

Academy of Pediatric Dentistry Council on Clinical Affairs 2015). However, this policy does not address the acceptable contact time of the gel with the dentition of young patients. Despite an abundant amount of information on the safety of at-home bleaching gels for adults, studies focused on the tolerable carbamide peroxide concentration and respective contact time with the tooth surface of young patients in terms of pulpal health are lacking. Stronger evidence may be needed to recommend tray whitening in child and teenage patients on a regular basis.

6.3.9.2 Tetracycline-Stained Teeth

Tetracyclines and their derivatives are broad-spectrum antibiotics active against both Gram-positive and Gram-negative bacteria as well as infections caused by mycoplasma, rickettsia, and chlamydia. They are also used in rheumatoid arthritis and chronic respiratory diseases and in the management of periodontal disease (Seymour and Heasman 1995; Tilley et al. 1995; Sánchez et al. 2004; Tredwin et al. 2005). Tetracyclines are contraindicated during pregnancy because they cross the placenta and are toxic to the developing fetus (Sánchez et al. 2004), causing tooth discoloration and enamel hypoplasia if administered during the period of tooth development.

The affinity of tetracycline for dental tissues was first described by Shwachman et al. (1958–1959) in pediatric patients with cystic fibrosis of the pancreas treated with long-term antibiotic therapy. Soon thereafter Zegarelli et al. (1960) reported similar findings in 38 of 52 children with cystic fibrosis of the pancreas treated with tetracycline. In 1962 Davies and co-workers suggested that tetracycline is deposited on the organic matrix of the bones and teeth prior to calcification (Davies et al. 1962). The fluorescence of the pigment and the histological findings confirmed the clinical observation that the pigmentation was due to tetracycline (Wallman and Hilton 1962). When 50 out of 64 newborns that had been given tetracycline during the neonatal period were followed up, 46 of them were found to have yellow or brown discoloration of the teeth, with or without enamel hypoplasia. The greater the total dose of tetracycline per birth weight, the greater the change was. The severity of the stain and its pattern depend on the tetracycline type, dosage, and duration of therapy (Wallman and Hilton 1962).

The affinity of tetracycline for mineralizing tissue is the result of its binding to calcium to form a tetracycline-calcium orthophosphate insoluble complex (Gassner and Sayegh 1968; Eisenberg 1975). Chelation with iron has also been reported for tetracycline-induced tooth discoloration (Salman et al. 1985; Bowles and Bokmeyer 1997). The teeth with tetracycline deposits emit yellow fluorescence when observed under ultraviolet light in a darkened room as opposed to the bluish fluorescence characteristic of nonpigmented teeth. The tetracycline stain undergoes degradation by exposure to light which results in gradually darker stains with age (Abou-Rass 1988).

In 1978 it was reported that minocycline was a viable alternative to treat cases of acne that did not respond to treatment with tetracyclines (Cullen 1978). Minocycline is a semisynthetic tetracycline derivative used for the treatment of acne and for those suffering from rheumatoid arthritis and chronic respiratory infections (Tilley et al.

1995; Tredwin et al. 2005). In a 1980 letter to the editor of the Journal of the American Academy of Dermatology, a dermatologist described a 42-year-old patient who had been on minocycline, 100 mg two to three times a day, for approximately 4–5 years (Caro 1980). The patient's dental hygienist had noted the development of a gray discoloration of the teeth. Additionally, the patient also stated that she retained a tan for longer than normal and that the skin and fingernails had a gray appearance. The patient's dental crowns had to be re-stained to match the gray color of the natural dentition. In 1985 a retrospective cohort study found that 4 of 72 patients who had minocycline therapy during adolescence had minocycline-associated tooth discoloration, which occurred after only 4 weeks of treatment in 1 case (Poliak et al. 1985). Other cases of posteruptive tooth staining with minocycline have been described (Salman et al. 1985; Bowles and Bokmeyer 1997; Cheek and Heymann 1999). Discoloration caused by minocycline is usually green-gray/blue-gray (Tredwin et al. 2005). Besides discoloration of the teeth, minocycline may also cause a blue staining of the sclera, ears, and oral mucosa, which may be irreversible (Dodd et al. 1998; LaPorta et al. 2005; Johnston 2013). Minocycline also causes discoloration of non-vital teeth (Dabbagh et al. 2002; Kim et al. 2010).

The esthetic management of patients with tetracycline-stained teeth is challenging as the degree of staining varies from mild to severe (Jordan and Boksman 1984).

1. Mild tetracycline staining (Fig. 6.11), usually very receptive to whitening. This staining is yellow to gray with minimal or no banding and is uniformly spread throughout the tooth, but more confined to the incisal three-quarters of the crown.
2. Moderate tetracycline staining (Fig. 6.12) may vary from a uniform deep yellow discoloration, which is responsive to bleaching, to a dark gray discoloration band located between the cervical fifth of the crown and the tooth surface located incisal to the band.

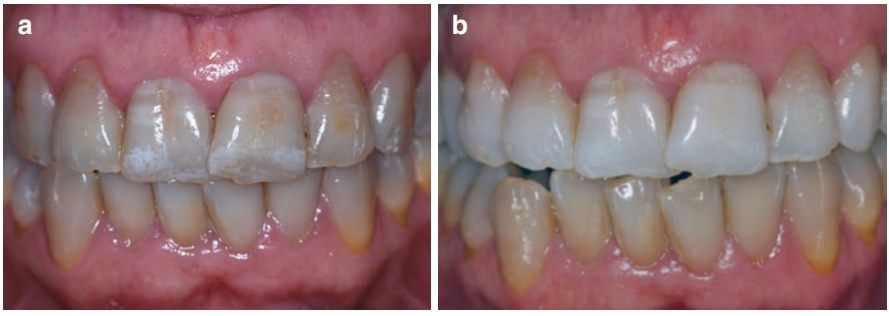

Fig. 6.11 (**a**) A 38-year-old patient with a history of tetracycline ingestion. Patient was diagnosed with mild tetracycline staining. Additionally, the maxillary central incisors had enamel white spots in the incisal third. (**b**) After 3 months of at-home whitening with 10% carbamide peroxide with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray with monthly recalls. Both the tetracycline stains and the white spot areas were successfully camouflaged despite a residual gray area in the cervical third

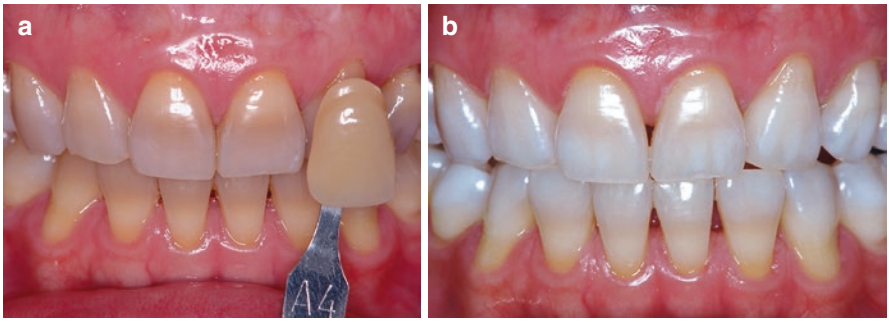

Fig. 6.12 (**a**) A 23-year-old patient with a history of antibiotic intake during childhood. Although the patient did not recall which type of antibiotic was prescribed, the clinical exam suggested that the discoloration was compatible with tetracycline staining. (**b**) After 4 months of at-home whitening with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) overnight in a custom-fitted tray. Patient returned to the clinic for monthly recalls. Patient did not experience any sensitivity or any other side effects

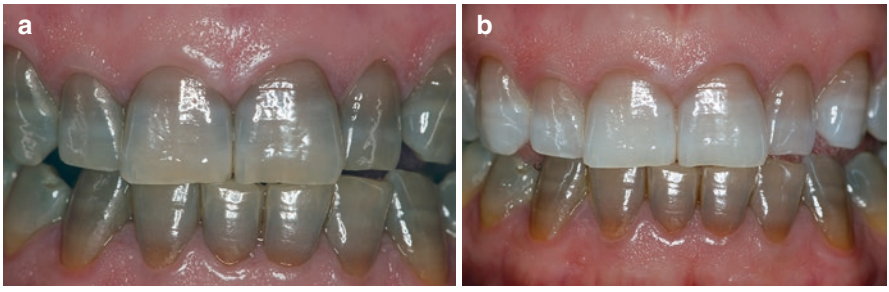

Fig. 6.13 (**a**) Severe tetracycline staining in a 42-year-old patient. (**b**) After 6 months of at-home whitening with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray with monthly recalls. As expected, and as the patient had been informed, the cervical third was the area most resistant to whitening

3. Severe tetracycline staining (Fig. 6.13) appearing blue-gray or dark gray, accompanied by significant banding across the tooth. Although whitening will somehow lighten these teeth, they may not become esthetically acceptable without bonded restorations.

Clinical studies have demonstrated that mild to moderate tetracycline stains can be removed relatively well (Figs. 6.4, 6.11, and 6.12) using the at-home bleaching technique with carbamide peroxide in a custom-fitted tray, even though an extended treatment time for up to 6 months may be required to achieve satisfactory results (Leonard et al. 2003). The recommended treatment is 2–6 months with monthly recalls to evaluate the tooth color and potential side effects (irritation of soft issues, exacerbation of symptoms from TMJ disorders, and tooth sensitivity). The stains located at the cervical third are the most difficult to remove. If no color

improvement is observed within the first 3 months, it is unlikely that any improvement will occur (Deliperi et al. 2006). Patients must be informed that a residual gray stain may still be perceptible around the cervical third of the teeth after the treatment. These clinical cases may need a longer bleaching regimen (Matis et al. 2006). The maximum lightening effect occurs during the first month of bleaching in tetracycline-stained teeth (Matis et al. 2006).

Patients with tetracycline-stained teeth participated in a clinical trial of at-home bleaching with 10% carbamide peroxide in a custom-fitted tray for 6 months. The 90-month follow-up determined the color stability, posttreatment side effects, and patient satisfaction (Leonard et al. 2003). *Shade was stable at least 90 months after treatment*. Patients in this study were overwhelmingly positive about the procedure in terms of shade retention and lack of posttreatment side effects, as 60% of the subjects reported no obvious shade change or only a slight darkening not noticed by others.

A total of 44 subjects in another study bleached their tetracycline-stained teeth overnight for 6 months using trays with reservoirs and then followed for up to 5 years. This was a split-mouth design study that used two of three different concentrations of carbamide peroxide in each patient – 10%, 15%, or 20%. More than 65% of the maximum tooth whitening remained for all carbamide peroxide concentrations after 5 years. However, 15% and 20% carbamide peroxide caused significantly more sensitivity than 10% carbamide peroxide (Matis et al. 2006). In this study there was a reversal of color change in tetracycline-stained teeth at 5 years.

- Although at-home whitening with 10% carbamide peroxide for up to 6 months remains the first treatment option for tetracycline-stained teeth, some patients may need to re-bleach or touch-up the tooth color approximately 5 years after the original treatment.

6.3.9.3 Teeth Stained from Fluorosis

Excessive fluoride intake may result in dental fluorosis, which is a hypomineralization of enamel characterized by opaque white areas or discolorations ranging from yellow to dark brown (Horowitz et al. 1984). The severity of fluorosis is correlated with the amount and duration of fluoride ingestion during tooth development (Robinson and Kirkham 1990). The enamel surface becomes pitted, displaying porosities on the surface in more severe cases. The degree of enamel hypomineralization may vary on different parts of the tooth surface due to the variation in enamel thickness (Fejerskov et al. 1990).

Dental fluorosis was described as *mottled teeth* by McKay and Black (1916), as fluoride had not yet been recognized as the cause for this discoloration. McKay and Black summarized very precisely the characteristics of mottled teeth including "the suspicion which is thrown on the water supply in the causative relation" and "localization in definite geographical areas, and its occurrence in the native children thereof."

The efficacy of at-home bleaching to treat discolorations associated with fluorosis depends on the stain (Haywood 2003). At-home whitening usually lightens

enamel brown stains (Figs. 6.5 and 6.14), but it may not work for severe cases with scores 5, 6, or 7 in the Tooth Surface Index of Fluorosis or TSIF (Horowitz et al. 1984). At-home bleaching is not very effective either to mask white opaque stains caused by fluorosis (Bodden and Haywood 2003; Perdigao 2010). However, not all white or brown spots are caused by fluorosis and may be considered idiopathic (Cutress and Suckling 1990; Gomes et al. 2006; Croll 2009). The term enamel "dysmineralization" has been used when referring to fluorosis-like enamel discolorations (Croll 1990).

When the enamel white spot lesions are superficial (< 0.5 mm), tray whitening may camouflage the white spots without the need to mask these areas with other techniques (Fig. 6.11b). Conversely, at-home whitening may highlight the whitish areas in cases of deeper enamel white spots. A few applications of a microabrasion suspension (Croll and Cavanaugh 1986a, b; Croll 1997), which contains hydrochloric acid (HCl) and silicon carbide, may disguise the white spots (for more information on enamel microabrasion, please refer to Parts III and IV of this book). However, it is difficult to predict when enamel microabrasion will remove a stain completely from a tooth (Celik et al. 2013), as the defect may be deeper than microabrasion can reach. In fact, the microabrasion compound is applied by rubbing it onto the enamel surface removing a thin layer of enamel (Donly et al. 1992; Paic et al. 2008).

Resin infiltration after enamel etching with HCl is the current treatment modality best suitable for white spots (Paris and Meyer-Lueckel 2009; Senestraro et al. 2013; Faghihian et al. 2019; Mazur et al. 2022). Robinson et al. (1976) introduced a combination of HCl enamel etching with the application of a low-viscosity resin as a potential cariostatic treatment. Originally this concept included etching enamel with HCl followed by infiltration with a resorcinol-formaldehyde resin. Among several early research papers on the topic of enamel etching with HCl followed by resin infiltration, it is worth highlighting two from the same research group. Paris et al. (2007) used confocal microscopy to study resin infiltration of carious lesions using 15% HCl to etch enamel, followed by immersion in ethanol for 30 sec and the application of a commercial dentin adhesive, ExciTE (Ivoclar Vivadent). In

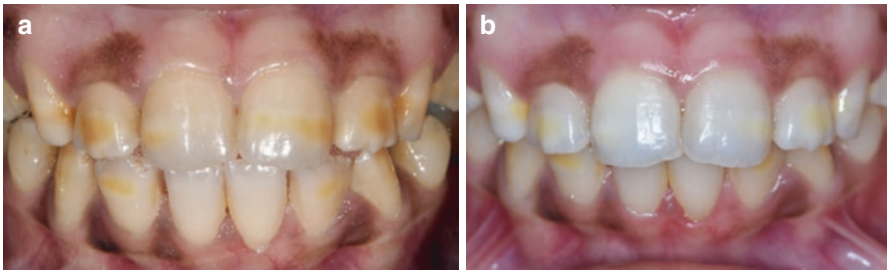

Fig. 6.14 (**a**) A 20-year-old patient with discolorations compatible with mild fluorosis. Patient was born in an area endemic for dental fluorosis. Patient was given the option of at-home whitening with 10% carbamide peroxide and was informed that there was a possibility that the stains would not be fully masked by the end of the treatment. (**b**) After 2 months of at-home bleaching with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray

2009, Paris and Meyer-Lueckel described the masking of enamel white spot lesions with resin infiltration using 15% HCl etching followed by a drying step with ethanol and a very-low-viscosity light-cured resin (tetraethylene glycol dimethacrylate).

6.3.9.4 Single-Tooth Discoloration from Calcific Metamorphosis of the Pulp

Traumatic injury of the pulp of vital teeth may result in calcific metamorphosis. The American Association of Endodontists (AAE) defines calcific metamorphosis as a pulpal response to trauma characterized by rapid deposition of hard tissue within the canal space; the entire space may appear obliterated radiographically due to extensive deposition, even though some portion of the pulp space remains in histological sections (American Association of Endodontists 2020).

The pulp produces reparative dentin that may obliterate partially or completely the entire pulp space (Holcomb and Gregory Jr 1967; Stroner and Van Cura 1984; Amir et al. 2001). The teeth with pulpal calcific metamorphosis are often more opaque and darker than the adjacent teeth (Figs. 6.6 and 6.15) and usually respond

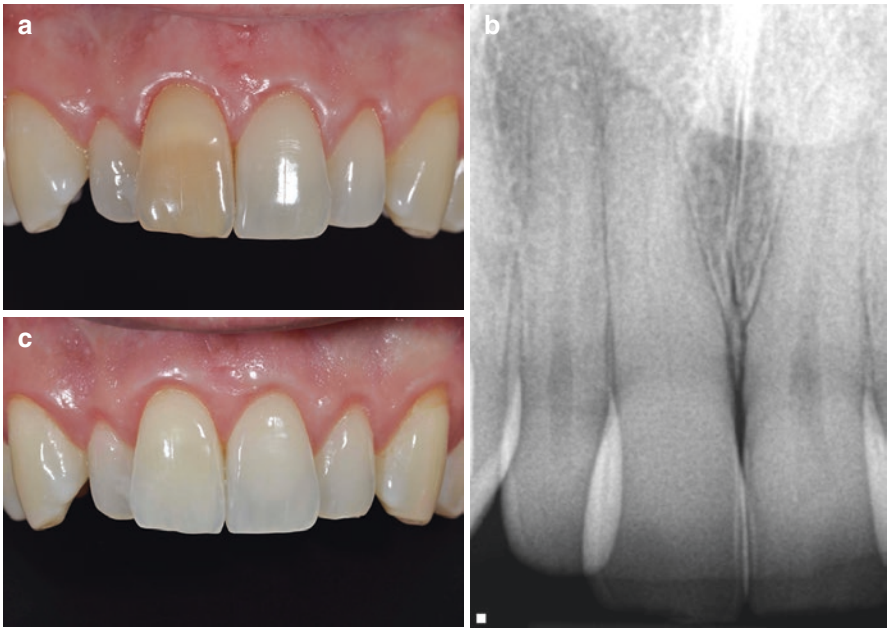

Fig. 6.15 (**a**) A 41-year-old patient with discolored tooth #8 (FDI 1.1) caused by a bike accident when the patient was 27 years old. (**b**) Periapical radiograph showing a calcified pulpal space on tooth #8 (FDI 1.1). The diagnosis was calcific metamorphosis. (**c**) After 5 weeks of tray whitening of tooth #8, the patient was extremely satisfied with the result. Patient only bleached the discolored tooth with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray using the technique described by Denehy and Swift (1992)

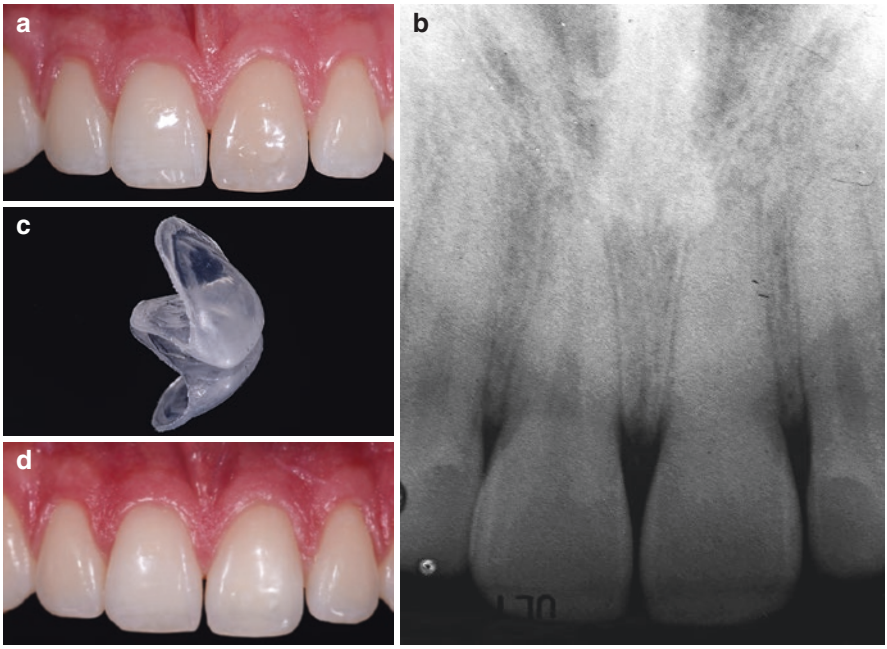

Fig. 6.16 (**a**) A 25-year-old patient with discolored tooth #9 (FDI 2.1) as a result of a sports traumatic injury. (**b**) After radiographic exam and clinical exam, the diagnosis was calcific metamorphosis. The tooth responded to cold stimulus applied from the lingual aspect. (**c**) One-tooth tray used to carry 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Whiteness Perfect 10%, FGM) into contact with the discolored tooth. (**d**) After 3 weeks of daily whitening for 4 h. This patient had decided that the overnight was not convenient

positively to thermal and electric pulp sensibility tests. The presence of reparative dentin does not usually result in delayed responses to the electric pulp test or EPT (Seltzer et al. 1963).

Denehy and Swift Jr (1992) described a method for bleaching discolored vital teeth with calcified pulpal spaces. The tray coverage of the adjacent teeth is trimmed to prevent their contact with the bleaching gel (Fig. 6.15). In case the patient desires to lighten the other teeth in addition to the tooth with calcific metamorphosis, these authors recommended making a new full-coverage tray to lighten the entire arch after bleaching the single discolored tooth (Denehy and Swift 1992). Another technique used for whitening individual teeth with discoloration caused by calcific metamorphosis uses an especially designed one-tooth tray (Fig. 6.16).

One-tooth whitening of the teeth with calcific metamorphosis is a very conservative treatment without the need to remove tooth structure. The teeth discolored from trauma bleach well, especially vital teeth, with no radiographic evidence of internal or periapical pathology.

6.4 Dentist-Supervised Jump-Start Bleaching Technique

The objective of the *jump-start* or combination technique is to boost the bleaching effect through a single session of in-office bleaching and then add the at-home tray bleaching component to allegedly reach a more esthetic result and improve color stability compared to at-home or in-office bleaching alone (Deliperi et al. 2004; Matis et al. 2009b; Nagarkar et al. 2022). This combined technique is also used to motivate patients and improve their compliance with the at-home treatment, as some whitening effect is observed immediately after the in-office treatment. The *jump-start* technique also improves the participants' satisfaction (Vaez et al. 2019; Kothari et al. 2020) and decreases the overall treatment time (Vaez et al. 2019). The clinical evidence, however, does not support the assumption that the combined technique results in better bleaching outcomes than sole at-home technique (Bernardon et al. 2010; Dawson et al. 2011; Cardenas et al. 2019). In addition, the combined technique results in a higher tooth sensitivity than the sole at-home technique (Cardenas et al. 2019) (For more details please refer to Chapter 7).

A more recent version of the *jump-start* technique has been advertised to treat more difficult cases (Kör Whitening, Evolve Dental Technologies, Inc.) (Sulieman 2008; Kör Whitening 2022a). This technique currently includes two versions of the combined or jump-start technique followed by periodic maintenance "for permanent results." As per the respective manufacturer, the trays included in the specific treatment regimen provide better sealing than conventional bleaching trays, enabling the whitening agent to be active all night as opposed to other tray whitening methods (Kör Whitening 2022a). The manufacturer's website also states that, "Clinical Research Associates (CRA) as well as other researchers have found that whitening gel in conventional whitening trays is only strongly active for 25-35 min. This is due to rapid contamination of the whitening gel by saliva." However, this statement is not supported by independent research. Although hydrogen peroxide releases all its peroxide in 30–60 min, with a quick decline, carbamide peroxide releases about 50% of its peroxide in 4 h and then experiences a slow decline (Haywood 2005). The percentage of carbamide peroxide recovered from the tray and teeth is 10% at 10 h (Matis et al. 1999).

Light sources that allegedly activate the peroxide during the in-office component of the jump-start technique have been used in many dental offices. According to Christensen (2003), "all whitening methods are successful to some degree"; but "the use of lights with bleaching has been mainly a marketing tool." According to recent systematic reviews and meta-analyses, light activation of in-office bleaching gel does not improve color change or affect tooth sensitivity independent of the concentration of hydrogen peroxide (Maran et al. 2018a, 2019).

- The clinical evidence does not show that the jump-start or combined technique results in better bleaching outcomes than the sole at-home technique.
- The jump-start technique results in more intense tooth sensitivity than the sole at-home technique.
- Light sources do not improve the outcomes of in-office bleaching used with the jump-start technique.

6.5 OTC Products for At-Home Bleaching Without Dental Professional Supervision

Sales of OTC bleaching products have increased dramatically in recent years driven not only by their lower cost compared to professional tooth whitening techniques but also by strong consumer demand for esthetic dental care and easy access through online auctions and e-commerce sites. Additionally, OTC bleaching products are easy to use and convenient for the patient (Kugel 2003). Concentrations as high as 45% carbamide peroxide are available from online auctions sites, drugstores, and e-commerce. Mall kiosks, salons, spas, and passenger ship cruises have also offered whitening treatments (ADA Council on Scientific Affairs 2010). Given that OTC bleaching trays are not custom-fitted to the patient's mouth, they are not the ideal vehicle for the application of peroxide-based gels. Ill-fitting trays may result in soft tissue injury, poor patient compliance, and malocclusion problems (Kugel 2003). In the European Union, the maximum concentration of peroxide allowed in toothpastes, mouth rinses, and other OTC products is 0.1% (European Commission Scientific Committee on Consumer Products 2007; European Union, Official Journal of the European Union 2011). For dentist-supervised bleaching, the maximum concentration of peroxide allowed is 6.0%.

How does the efficacy of OTC whitening products compare to that of dentist-prescribed at-home whitening? There are many studies comparing OTC with dentist-prescribed whitening. However, only a few independent clinical studies have been published (Serraglio et al. 2016). Bizhang et al. (2009) measured tooth shade with spectrophotometry and concluded that 6% hydrogen peroxide whitening strips applied twice a day for 30 min each for 2 weeks were not as effective as at-home whitening with 10% carbamide peroxide overnight for 2 weeks. A systematic review reported that when hydrogen peroxide bleaching strips were compared to at-home whitening, results varied for adverse reactions (tooth sensitivity and oral irritation). Some clinical studies included in this systematic review favored bleaching strips, while other studies favored the at-home regimen with carbamide peroxide. There were also some studies that did not show any differences between treatments (Eachempati et al. 2018). Another systematic review and meta-analysis (da Rosa et al. 2020) reported that the risk and intensity of tooth sensitivity were lower with bleaching strips; however, at-home bleaching supervised by a dental professional resulted in better color change when measured with a spectrophotometer. Several clinical trials included in systematic reviews were sponsored by a manufacturer of bleaching strips (Eachempati et al. 2018).

Kishta-Derani et al. (2007) evaluated four paint-on self-adhering solutions (films) brushed on the tooth surface. These paint-on films contained hydrogen peroxide, sodium percarbonate, or carbamide peroxide. Two of the paint-on films did not result in any significant whitening effect after two weeks of daily application.

For similar concentrations of hydrogen peroxide, OTC bleaching strips may cause more gingival irritation and tooth sensitivity than at-home tray whitening, as discussed in Chap. 4. However, as discussed in Chap. 5, bleaching strips with 10% HP result in about 13 times lower diffusion of H_2O_2 compared to that of 35% H_2O_2

gel used in in-office bleaching treatments (Soares et al. 2013). This may be explained by the reduced thickness of hydrogen peroxide contained in a whitening strip compared to the thickness used during in-office bleaching.

A recent clinical trial (Del Real García et al. 2019) compared a whitening strip with 10% hydrogen peroxide with a placebo strip without hydrogen peroxide, applied 30 min twice daily over a 10-day period. Samples of the oral mucosa were analyzed. The results showed that whitening strips with 10% hydrogen peroxide resulted in increased genotoxic and oxidative damage in oral epithelial cells.

Many toothpastes are currently marketed as having a whitening effect, but they are usually limited in their bleaching efficacy (Devila et al. 2020), as the contact time with the tooth structure is very low. Some toothpastes contain hydrogen peroxide. The respective bleaching effect is proportional to the concentration of hydrogen peroxide (Kim et al. 2020). Toothpastes with claims of bleaching potential typically contain an abrasive to remove and/or prevent surface stains, such as hydrated silica, calcium carbonate, dicalcium phosphate, dihydrate, calcium pyrophosphate, alumina, and sodium bicarbonate (Joiner 2010). These toothpastes are nevertheless useful to prevent tooth staining between recall appointments and prophylaxis. According to the European Commission Scientific Committee on Consumer Products (2007), most clinical studies with peroxide-containing toothpastes are sponsored by the respective manufacturers and rarely published.

The most recent OTC methods are activated charcoal powder, charcoal-containing toothpastes, and toothbrushes with charcoal-infused bristles. The current evidence shows that charcoal is not effective for tooth whitening but may trigger alterations to the enamel surface (Brooks et al. 2017; Franco et al. 2020; Palandi et al. 2020).

6.6 Side Effects of At-Home Bleaching

Chapters 4 and 5 include a comprehensive description of adverse effects caused by peroxide-based whitening agents.

In vitro studies have reported that while 10% carbamide gel does not result in relevant toxicity to odontoblast-like cells (Soares et al. 2011; Almeida et al. 2015), 16% carbamide peroxide increases the toxicity to the same type of cells (Soares et al. 2011). Although the clinical efficacy and safety of 10% carbamide peroxide is well documented (Matis et al. 1998; Swift Jr et al. 1999; Matis et al. 2000; Ritter et al. 2002; Leonard et al., 2003; Zekonis et al. 2003; Matis et al. 2009a; Meireles et al. 2009), vital tooth whitening causes side effects irrespective of the method. One study concluded that there were minimal clinical side effects up to 17 years after nightguard vital bleaching with 10% carbamide peroxide (Boushell et al. 2012). In this study the Löe's gingival index and external cervical resorption findings were considered within normal expectations.

- Two treatment-related predictors for side effects are bleaching gel concentration and contact time between the gel in the tray and the intraoral tissues.

6.6.1 Tooth Sensitivity

As this topic is discussed in more detail in Chaps. 4 and 5, we will discuss tooth sensitivity related to at-home whitening with a custom-fitted tray.

Transient tooth sensitivity is the most common lateral effect of tray whitening with peroxides. It results from the penetration of peroxides into the pulp space. The peroxide must be able to penetrate tooth structure to oxidize the tooth structure (please refer to Chap. 2 for details). The sensitivity that arises during the bleaching treatment occurs in intact teeth without any triggering stimulus mechanism. This sensitivity caused by peroxides is substantially different from the sensitivity caused by exposed dentin with patent dentinal tubules around the cervical area of the teeth. For the latter, dentin sensitivity is caused by a hydrodynamic mechanism of fluid shifts in the dentinal tubules that activate mechanosensitive nerve endings in the pulp and the predentin area (Brännström et al. 1967; Markowitz 2010). It has been known for many years that the pain caused by fluid shifts in the tubules can be treated by blocking the tubules (Gysi 1900; Brännström et al. 1979). On the contrary, sensitivity caused by peroxide-based bleaching materials does not respond to the treatments used for dentin sensitivity caused by patent dentinal tubules.

Two other factors could play a role in the onset of tooth sensitivity associated with tooth bleaching. First, the pH of bleaching gels used for the at-home technique can be as low as 5.6 (Price et al. 2000). The pH also varies for gels of similar concentration made by different manufacturers (Mailart et al. 2023). Second, bleaching gels contain Carbopol polymer as thickener (Basting et al. 2005), which makes the bleaching gel anhydrous therefore causing dentin desiccation by osmotic pressure. This may explain why a placebo bleaching gel without peroxide also causes tooth sensitivity (Jorgensen and Carroll 2002).

Sensitivity usually relapses upon termination of the treatment (Haywood 1997a). A higher incidence of sensitivity is associated with higher concentrations of carbamide peroxide (Matis et al. 2000; Basting et al. 2012). In a clinical study with carbamide peroxide gel in a tray 71% of subjects who used 20% carbamide peroxide reported tooth sensitivity, while only 37% of subjects who used 10% carbamide peroxide experienced tooth sensitivity (Basting et al. 2012). Patients may be advised that there is a higher chance that they will experience *severe* sensitivity with 20% carbamide peroxide than with 10% carbamide peroxide (Basting et al. 2012). Sensitivity tends to occur early in the treatment and diminishes with time.

There are a few predictors for tooth sensitivity associated with at-home whitening (Table 6.2). Patients with gingival recession are more likely to experience tooth sensitivity during home whitening treatment (Jorgensen and Carroll 2002). Other predictors are history of sensitive teeth, enamel craze lines, contact time of the bleaching agent with the teeth, changing of the bleaching gel by the patient more frequently than once a day, and the utilization of higher concentrations of carbamide peroxide as described before (Haywood 1997a; Leonard Jr et al. 1997; Gerlach et al. 2000; Cardoso et al. 2010; Basting et al. 2012; Özcan et al. 2014). In a clinical study in which patients used a 10% carbamide peroxide gel, subjects following a

Table 6.2 *Predictors* for tooth sensitivity during at-home whitening treatment

Gingival recession
History of sensitive teeth
Contact time of the bleaching gel with teeth
Replenishing the tray with bleaching gel
Concentration of carbamide peroxide >10%

bleaching regimen of 8 h daily experienced significantly more sensitivity than those who bleached for 1 h per day (Cardoso et al. 2010).

Peroxides diffuse very quickly into dentin reaching the pulp chamber, but the rate of penetration depends on the concentration, amount of bleaching gel, composition of the whitening agent, and the thickness of the hard tooth structure (Hanks et al. 1993; Thitinanthapan et al. 1999; Gokay et al. 2000). Some specific brands of 10% carbamide peroxide gels result in greater concentration of hydrogen peroxide within the pulp chamber than other similar concentrations, regardless of the diffusion time (Hanks et al. 1993). In extracted teeth, significantly less peroxide reaches the pulp from a 15% carbamide peroxide gel (equivalent to 5.25% hydrogen peroxide) than from a 5% hydrogen peroxide gel within a 15-min period (Cooper et al. 1992), which attests the lower rate of decomposition of the carbamide peroxide compared to that of hydrogen peroxide. When hydrogen peroxide is applied for periods longer than 15 min, it is capable of diffusing through 0.5 mm of patent dentin, damaging pulpal tissue (Hanks et al. 1993). Clinically, a depth of 0.5 mm corresponds to a deep area in non-carious cervical lesions. In case the teeth are already sensitive prior to starting the treatment, the dentin tubules may be patent which would make bleaching contraindicated. Pulpal tissue has limited volume to expand from injury; therefore, it may have a compromised response to inflammatory stimuli because of pressure associated with edema, causing sensitivity (Heyeraas and Kvinnsland 1992). In case heat is used or produced during the treatment, such as in-office bleaching with light (including the jump-start technique), pulpal enzymes may be significantly inhibited (Bowles and Thompson 1986).

Manufacturers have added potassium nitrate and sodium fluoride to the composition of their whitening gels to prevent sensitivity during at-home bleaching treatment. Carbamide peroxide gels for the at-home technique typically contain 0.11% (w/w) fluoride and 3% (w/w) potassium nitrate (Chen et al. 2008). The use of sodium fluoride daily after bleaching does not affect the bleaching efficacy of carbamide peroxide but may reduce the intensity of tooth sensitivity (Armênio et al. 2008). The application of a 5% potassium nitrate and fluoride gel in the bleaching tray has been shown to reduce the incidence of tooth sensitivity in patients undergoing at-home whitening with 10% carbamide peroxide in a custom-fitted tray (Haywood et al. 2001).

Clinical studies have reported that potassium nitrate and sodium fluoride added to a 10% carbamide peroxide gel reduced sensitivity over a 2-week at-home treatment when compared to a 10% carbamide peroxide gel without desensitizer (Tam 2001; Browning et al. 2008; Navarra et al. 2014). The application of 3% potassium nitrate and 0.11% fluoride desensitizing agent for 30 min prior to at-home whitening with 10% carbamide peroxide decreases tooth sensitivity when compared with

a placebo in a population at risk for tooth sensitivity (Leonard et al. 2004). Another clinical trial reported that the use of 5% potassium nitrate and 2% sodium fluoride prior to at-home vital bleaching with 16% carbamide peroxide did not affect the bleaching efficacy but reduced the number of days during which patients experienced tooth sensitivity (Kose et al. 2011). A Cochrane Database systematic review reported that carbamide peroxide with potassium nitrate as desensitizer showed significantly less sensitivity compared to carbamide peroxide gel without the desensitizer (Eachempati et al. 2018). To corroborate the effectiveness of potassium nitrate and sodium fluoride, their use prior to in-office bleaching with 35% hydrogen peroxide also reduces tooth sensitivity significantly (Tay et al. 2009; Wang et al. 2015). However, a randomized clinical trial with 10% carbamide peroxide with 3% potassium nitrate and 0.2% sodium fluoride for at-home bleaching did not reduce tooth sensitivity compared to the same concentration without the desensitizing agent (Maran et al. 2018b).

Clinicians have recommended brushing with potassium nitrate-containing toothpaste for 2 weeks before initiating the at-home whitening treatment with a custom-fitted tray. This pre-treatment has been shown to be beneficial to patients by reducing tooth sensitivity during whitening (Haywood et al. 2005). However, this regimen needs to be tested in randomized clinical trials. Dentists have also recommended the application of the desensitizing toothpaste in the bleaching tray for up to 30 min (Haywood 2003). This recommendation may not be safe, as the toothpaste may contain ingredients that cause soft tissue reactions when the toothpaste is left in contact with the soft tissue longer than when the toothpaste is used for tooth brushing.

Other desensitizers have been used. A clinical study compared the efficacy of two desensitizers included in the composition of carbamide peroxide gels. Potassium nitrate was found to be as effective as amorphous calcium phosphate (ACP) to prevent sensitivity (Matis et al. 2007). However, 15% carbamide peroxide gel with potassium nitrate and sodium fluoride achieved significantly better whitening results than a 16% carbamide peroxide gel with amorphous calcium phosphate (ACP) (Matis et al. 2007). When comparing potassium nitrate with potassium oxalate as desensitizers included in the composition of 10% carbamide peroxide gels, it was reported that the gel with potassium oxalate caused significantly more sensitivity at 1 week than the 10% carbamide peroxide gel with potassium nitrate or 10% carbamide peroxide gel without any desensitizer (Perdigao et al. 2013).

- Brushing with potassium nitrate-containing toothpaste for 2 weeks prior to the bleaching treatment has been suggested to reduce tooth sensitivity during the treatment.
- Potassium nitrate is the recommended desensitizer to use with at-home whitening treatments (Tam 2001; Matis et al. 2007; Wang et al. 2015), as it reduces postoperative sensitivity without reducing efficacy when added to carbamide peroxide gels (Browning et al. 2008; (Eachempati et al. 2018).
- The penetration of peroxides into dentin may be reduced by the application of a desensitizing agent or a fluoride varnish (Hannig et al. 2011).

6.6.2 Pulp Injury

Because this topic is extensively and elegantly discussed in Chap. 5, we will only cite three studies that suggest the relatively innocuous nature of 10% carbamide peroxide to the human pulp. To study the pulp injury potential of 10% carbamide peroxide, an ex vivo study included 16 patients who had 4 premolars scheduled to be extracted for orthodontic reasons (Fugaro et al. 2004). Tooth #5 was bleached for four days, tooth #12 was treated for two weeks, tooth #21 was bleached for two weeks followed by two weeks without treatment, and tooth #28 was not treated, serving as the control. All whitening treatments were performed overnight with 10% carbamide peroxide. All teeth were extracted at the same time and prepared for histological evaluation at two different research centers. Slight pulpal changes caused by 10% carbamide peroxide were detected in 16 of the 45 bleached teeth. Neither moderate nor severe reactions were observed. The slight histological changes sometimes observed after bleaching tend to resolve within two weeks posttreatment (Fugaro et al. 2004).

The apparent safety of nightguard vital bleaching may be due to the response by odontoblasts with increased heme oxygenase-1 (HO-1) production. Seventeen intact first premolars scheduled for orthodontic extraction were bleached with 10% carbamide peroxide for 4 h immediately preceding extraction. Fourteen additional premolars from the same individuals were not bleached. Upon extraction and histological evaluation, no significant differences were found in the concentration of the enzyme HO-1 in the pulp, which is normally increased in cells subjected to oxidative stress (Anderson et al. 1999).

As described in Chap. 5 with great detail, in-office bleaching is more deleterious to the pulp-dentin complex than at-home bleaching with carbamide peroxide. Vaz et al. (2016) reported that in-office bleaching with 38% hydrogen peroxide resulted in more intense inflammation and greater pulp damage than at-home bleaching with 15% carbamide peroxide. Please refer to Chap. 5 for in-depth information on the topic of pulp injury caused by peroxides.

6.6.3 Decreased Bonding Effectiveness

Peroxide bleaching materials significantly decrease the bond strength of resin-based composite to bleached enamel and dentin (Cavalli et al. 2001; Shinohara et al. 2005). The bond strengths of composite to etched enamel are reduced after bleaching with 10% carbamide peroxide (Cvitko et al. 1991; Barghi and Godwin 1994; Ben-Amar et al. 1995; Spyrides et al. 2000), in addition to increased enamel surface porosity (Ben-Amar et al. 1995). The reduction in bond strengths may be as high as 76% of the bond strengths to unbleached enamel (Spyrides et al. 2000). Removal of surface enamel prior to bonding restores bond strengths to normal level (Cvitko et al. 1991). The use of acetone-based adhesives or drying agents, such as 70% alcohol and acetone, may also restore bond strength of resin composite to enamel immediately after bleaching (Barghi and Godwin 1994; Niat et al. 2012).

The enamel and dentin bond strengths remain low for the first two weeks post-bleaching. The bond strengths return to the level of untreated substrates after 2 weeks (Cavalli et al. 2001; Shinohara et al. 2005). Increased concentration of carbamide peroxide did not extend the time needed prior to bonding. The same restriction during the first weeks applies to internal bleaching of root-filled teeth, including adhesion to calcium silicate-based materials (Tsujimoto et al. 2011; Keskin et al. 2019; Sismanoglu et al. 2022).

- Dental professionals must wait for at least 2 weeks after the patient completes the whitening treatment prior to performing any adhesive restorative procedure.

Resin-enamel interfaces in enamel bleached with 10% carbamide peroxide exhibit extensive nanoleakage compared to those of the unbleached control group (Lai et al. 2002). Reduction of resin-enamel bond strength in bleached etched enamel may be caused by a delayed release of oxygen that affects the polymerization of resin components (Lai et al. 2002). Although enamel bond strengths to bleached enamel are reduced after bleaching, this reduction can be reversed with treatment with an antioxidant prior to bonding, such as 10% sodium ascorbate (Lai et al. 2002; Türkün and Kaya 2004).

6.6.4 Changes in Physical Properties and Ultra-morphology of Enamel and Dentin

Most studies indicate that peroxide-based bleaching agents have no *permanent* significant deleterious effects on enamel and dentin surface morphology, surface microhardness, and chemical composition (Sulieman et al. 2004; Joiner 2007), while other studies show enamel erosions and changes in the enamel structure (Haywood et al. 1991; Shannon et al. 1993; Bitter 1998; Barros Júnior et al. 2022). Microhardness has been the most frequently used method for evaluating the effects of peroxides on enamel and dentin (Joiner 2007). Lopes et al. (2002) found no adverse effects on enamel microhardness and surface morphology with 10% carbamide peroxide, but bleaching with 3% hydrogen peroxide negatively affected the enamel hardness and surface morphology, which may have been a result of the lower pH of the hydrogen peroxide material. Barros Júnior et al. (2022) reported that at-home bleaching with 22% carbamide peroxide in vitro did not affect surface roughness when used for 1 h per day for 4 weeks, which the authors considered "excessive bleaching." However, the treatment decreased enamel microhardness. Other authors (Efeoglu et al. 2007) measured a significant reduction in the mineral content of the enamel surface (but not dentin) after bleaching with 35% hydrogen peroxide for 2 h.

It has been reported that peroxides increase the porosity of enamel (Ben-Amar et al. 1995), alter the chemical composition of dentin (Rotstein et al. 1992), reduce the ultimate strength of enamel (Cavalli et al. 2004; da Silva et al. 2005), reduce the flexural strength and flexural modulus of dentin (Tam et al. 2005), and induce morphological alterations in the hydroxyapatite crystallites (Perdigao et al. 1998; Perdigao and Lopes 2006).

A study tested the effects of the Carbopol polymer and glycerin (separately and in association) on the physical properties of enamel and dentin in addition to the effects of 10% carbamide peroxide (Basting et al. 2005). The baseline microhardness was not recovered during the 14-day posttreatment phase. All the materials tested and their associations changed the microhardness of dental tissues, even in the presence of artificial saliva. There was a tendency towards lower microhardness after treatment with the Carbopol polymer.

The change in chemical composition of dentin postbleaching may be due to a reduction of the organic component in dentin (Rotstein et al. 1992). Treatment with 30% hydrogen peroxide causes changes in the chemical structure of the dentin and cementum, making them more susceptible to degradation. Exposure to 30% hydrogen peroxide for 24 h also causes a significant decrease in the hardness and Young's modulus of intertubular dentin, as measured with AFM and nanoindentation (Chng et al. 2005). The effect of hydrogen peroxide on dentin may be a result of both its strong oxidizing action and its low pH. Peritubular dentin is more resistant to the effects of hydrogen peroxide than intertubular dentin, which may be caused by the higher mineral content of the former. Enamel treatment with carbamide peroxide for 6 h per day for 14 days, followed by storage in artificial saliva in between each application, resulted in a significant reduction of the ultimate tensile strength of enamel, regardless of the concentration of carbamide peroxide (10%, 15%, 16%, and 20%) (Cavalli et al. 2004).

Another study (da Silva et al. 2005) evaluated the effects of peroxide bleaching regimens on the ultimate tensile strength of human enamel. All different bleaching procedures (7.5% hydrogen peroxide, 30 min per day for 14 days; 10% carbamide peroxide, 6 h per day for 5 days; 10% carbamide peroxide, 6 h per day for 14 days; 35% carbamide peroxide, 2 applications of 30 min with a 5-day interval between applications; 37% carbamide peroxide, 2 applications of 30 min with a 5-day interval between applications; 35% hydrogen peroxide, 2 applications of 15 min with a 7-day interval between applications) significantly reduced enamel ultimate tensile strength. This reduction in the ultimate tensile strength was accompanied by changes in the enamel internal micromorphology, with a possible loss of interprismatic matrix, and the presence of porosities at the prism-fractured ends in the bleached fractured enamel might indicate that some intraprismatic material was also lost. These features were more pronounced in the group treated with 35% hydrogen peroxide.

Different at-home whitening regimens with several concentrations of carbamide peroxide have also been shown to reduce both the flexural strength and flexural modulus of dentin (Tam et al. 2005). This reduction was not observed for in-office

treatment with hydrogen peroxide possible due to the shorter treatment time compared to that of carbamide peroxide.

Ultra-morphological studies with scanning and transmission electron microscopy (Perdigao et al. 1998; Perdigao and Lopes 2006) revealed that the treatment of enamel with 10% carbamide peroxide did not result in changes in the morphology of the crystallites immediately below the enamel surface (Fig. 6.17), but this alteration was pronounced when enamel was treated with 38% hydrogen peroxide following the recommendations for in-office whitening (Perdigao and Lopes 2006). This is in agreement with other authors, who found that the most severe changes in enamel topography occurred with products of lower pH (Shannon et al. 1993). The periphery of the crystals was not well defined as in the control group denoting a mottled etched pattern and loss of structural arrangement.

When the teeth are exposed to a 10% carbamide peroxide gel for 6 h they lose 1 μg/mm^2 of calcium. If the teeth are exposed to a cola beverage for 2.5 min (the time equivalent to drinking a 16 oz. beverage) the amount of calcium lost from these teeth is also 1 μg/mm^2 (McCracken and Haywood 1996). Orange juice causes more

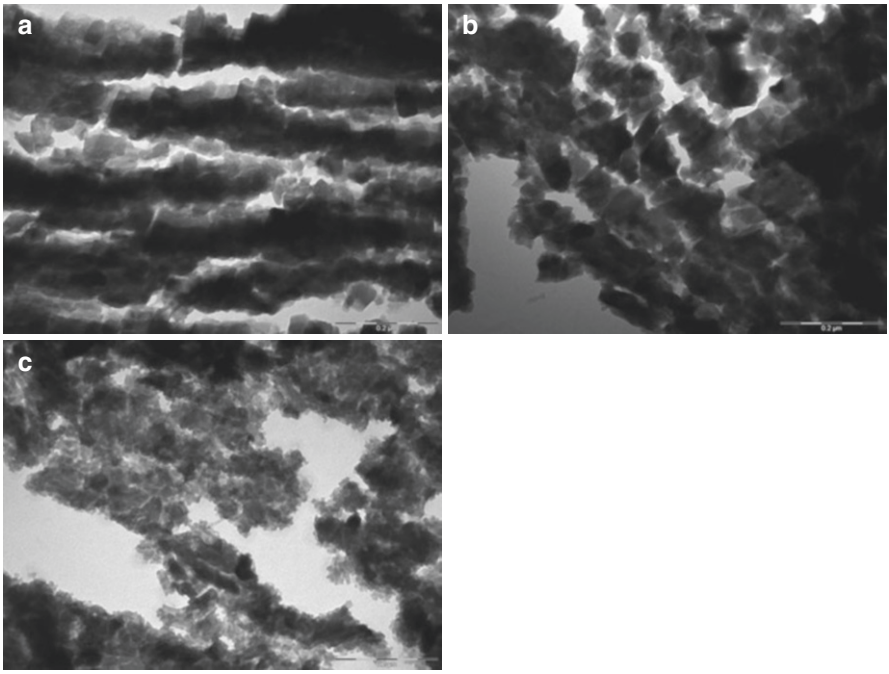

Fig. 6.17 (**a**) Transmission electron micrograph of untreated human enamel. Original magnification = ×150,000. (**b**) Transmission electron micrograph of human enamel bleached with 10% carbamide peroxide gel (Opalescence 10%, Ultradent Products) for 2 weeks, 8 h daily. Specimens were stored in artificial saliva at 37 °C between bleaching sessions. Original magnification = ×150,000. (**c**) Transmission electron micrograph of human enamel bleached with 38% hydrogen peroxide (Opalescence Xtra Boost, Ultradent Products), four consecutive applications of 15 min each. Original magnification = ×150,000

harm to enamel surfaces than whitening materials do (Sulieman et al. 2004). Therefore, *adverse effects on enamel and or dentin caused by whitening materials may reflect the pH of the formulation rather than the bleaching agent itself* (Sulieman et al. 2004). Some of these alterations caused by peroxide bleaching materials on the dental hard tissues may be transient and reversed when treated with a fluoride solution.

The data obtained in all the in vitro studies mentioned in this section may have to be analyzed with caution. The clinical relevance of some of the methods used to assess the effects of peroxides on dental hard tissues may not reflect the clinical conditions accurately. Studies have used whitening agents of low pH, which may have caused microscopic erosion and other alterations of the substrate that were not accounted for in the research methodology (Joiner 2007).

6.7 Recommendations

- Refrain from being too optimistic when predicting the posttreatment tooth color.
- If the patient's shade falls in the C or D range in the Vita Classical A1–D4 shade guide, the result will not be as pleasant as that for patients in the A or B shade range.
- Prescribe 10% carbamide peroxide with desensitizer in the bleaching gel.
- Recommend that patient wears the bleaching tray preferably overnight.
- Inform patient that sensitivity is likely to occur; prescribe potassium nitrate-containing toothpaste to replace patient's regular toothpaste. This toothpaste may be more effective if used during 2 weeks prior to starting the bleaching regimen.
- The application of a gel of potassium nitrate and sodium fluoride prior to at-home bleaching decreases tooth sensitivity and reduces the number of days during which patients experience tooth sensitivity.
- Give patient written instructions:
  - Brush and floss before placing the tray.
  - Insert the tray snugly over the teeth; gently tap the tray to move the gel into place and adapt tray to the teeth.
  - Watch for excess gel along the tray border; remove it with a toothbrush or with a cotton swab. Rinse your mouth with water, and do not swallow the gel.
  - Wear tray for the time recommended.
  - Brush and floss after removing the tray; wash tray thoroughly with water to remove the residual gel.
- Smokers may need to refrain from smoking from 2 h prior to inserting the tray in the mouth to 2 h after removing the tray.

6.8 FAQ

To summarize the contents of this chapter, we present below a series of questions and answers on the topic of at-home whitening.

6.8.1 Patients

Do I need to refrain from a potentially staining diet during and after tray bleaching?

Current evidence from controlled clinical trials suggests that coffee, tea, and red wine do not interfere considerably with the outcome of bleaching.

Is it OK that I wear my tray filled with 10% carbamide peroxide for 2 h per day?

It will take longer to achieve the desired lightening effect compared to bleaching overnight. Current clinical evidence suggests that overnight tray bleaching results in whiter teeth and more durable results than bleaching for a few hours during the daytime.

My teenage daughter wants to have her teeth bleached. Is it safe?

As discussed in Sect. 6.3.9.1 "Physiological Discoloration," we may need stronger evidence to recommend tray bleaching in child and teenage patients.

I have some yellowish tooth-colored fillings in my front teeth. Will they get whiter if I bleach my teeth?

They may look slightly lighter because of the oxidation of the surface pigment (Fig. 6.10c), but in most cases tooth-color filling materials will not bleach (Fig. 6.8). Existing tooth-colored fillings (resin-based composite restorations) may need to be replaced after the bleaching treatment is completed to make your smile look better.

How does the efficacy of OTC bleaching products compare to that of the dentist-prescribed at-home bleaching?

One of the very few independent studies mentioned earlier in this chapter concluded that 6% hydrogen peroxide bleaching strips applied twice a day for 30 min each for 2 weeks are not as effective as at-home bleaching with 10% carbamide peroxide overnight for 2 weeks. Another study concluded that some paint-on products are ineffective. OTC bleaching strips may cause more tooth sensitivity and gingival irritation than at-home tray bleaching prescribed by a dental professional.

In summary, at-home bleaching with 10% carbamide peroxide in a custom-fitted tray is safer and more effective than OTC bleaching treatments. The results obtained with OTC bleaching are not as pleasant, and the procedure is not as safe as those methods currently prescribed by a dental professional.

6.8.2 Dental Professionals

You usually prescribe 10% carbamide peroxide for your clinical cases of at-home bleaching in a custom-fitted tray. Do higher concentrations of carbamide peroxide result in whiter teeth? What is the evidence?

Current evidence from controlled clinical trials suggests that higher concentrations induce a faster rate of bleaching than lower concentrations with a similar final result. At 1 year, 16% carbamide peroxide concentration does not increase the longevity of the bleaching effect compared to 10% carbamide peroxide. Lower concentrations of carbamide peroxide result in lower incidence of sensitivity than higher concentrations.

Dentist-prescribed overnight bleaching with carbamide peroxide in a custom-fitted tray is the safest and most effective method of tooth bleaching as reported in several clinical studies mentioned in this chapter. The durability of the bleaching effect is another factor that needs to be considered. Patients who had bleached their teeth using 10% carbamide peroxide in a custom-fitted tray were contacted at least 10 years posttreatment. Patient satisfaction with tray bleaching was determined to last an average of 12.3 years posttreatment.

What concentration of peroxide is best for our patients?

From the previous question/answer, the efficacy of 10% carbamide peroxide is similar to that of higher concentrations. We only recommend 10% carbamide peroxide, except for some cases of external bleaching of discolored endodontically treated teeth in which the stain is recent.

Do you also perform in-office bleaching? Or do you only prescribe at-home bleaching?

Some patients elect not to be treated with at-home tray bleaching for several reasons. We always inform these patients that they can opt for in-office bleaching, but that several sessions may be needed to obtain an acceptable final tooth color. Patients must also be informed that in-office bleaching is more likely to cause tooth sensitivity than at-home bleaching with a custom-fitted tray. Other potential adverse effects of in-office bleaching with >30% hydrogen peroxide are described in Chaps. 4, 5, and 7.

Does fluoride help prevent sensitivity during my treatment?

The use of sodium fluoride daily after bleaching does not affect the bleaching efficacy of carbamide peroxide and may reduce the intensity of tooth sensitivity.

What is the recommended duration of at-home bleaching treatments?

We currently inform our patients that discolorations caused by aging and chromogenic foodstuff usually achieve a satisfactory lighter color after 2–4 weeks of overnight tray bleaching with 10% carbamide peroxide. However, this result depends on the patient's compliance. The ideal final color is not reached if the patient does not wear the tray daily. For gray tooth shades, C's and D's in the Vita Classical A1–D4 shade guide, we recommend 4–6 weeks of overnight tray bleaching with 10% carbamide peroxide, with the prospect of a residual darker area at the cervical third of the teeth.

What is the best desensitizing agent to use with peroxides?

There is evidence that the desensitizer that has been shown to reduce sensitivity during bleaching treatment is potassium nitrate. The combination of potassium nitrate with sodium fluoride in toothpaste may prevent tooth sensitivity when used for 2 weeks prior to starting the bleaching treatment or as a gel when applied 30 min prior to inserting the bleaching tray. The inclusion of potassium nitrate in the

composition of the carbamide peroxide bleaching gel may also help in the prevention of tooth sensitivity.

Is the jump-start technique more efficient than the at-home technique alone?

Current evidence from controlled clinical trials and systematic reviews suggests that tray bleaching alone results in similar results compared to the *jump-start* technique. However, some clinicians claim that the jump-start technique motivates patients, as the initial results are visible immediately after the initial in-office bleaching component.

Can tetracycline-stained teeth be bleached with at-home bleaching regimen using a carbamide peroxide gel?

Yes, but it depends on the intensity of the stain. Very dark stains are more difficult to bleach as described in Sect. 6.3.9.2 "Tetracycline-Stained Teeth."

Do dentists have to wait for 2 weeks after the conclusion of the bleaching treatment before they can place bonded restorations on recently bleached teeth? Does it apply to internal and to external bleaching?

Yes. It applies to all peroxide-based bleaching regimens and techniques.

How do we know that the concentration written on the syringe corresponds to the concentration of peroxide inside the syringe?

The chance of a mismatch between the advertised concentration and the actual concentration is very high. For bleaching some gels, the actual concentration is between 16% and 36% lower than the label indicates.

I heard at a dental convention and recently read on a manufacturer's site that gel in conventional bleaching trays is only strongly active for 25–35 min.

More than 50% of the active agent is available after 2 h. The percentage of carbamide peroxide recovered from the tray and teeth is 10% at 10 h.

Does at-home bleaching affect the vitality of the pulp?

For in-depth information on pulpal inflammation triggered by peroxide-based bleaching agents, please refer to Chap. 5. In case heat is used, such as in the jump-start technique, pulpal enzymes may be significantly inhibited.

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References

Abou-Rass M (1988) Long-term prognosis of intentional endodontics and internal bleaching of tetracycline-stained teeth. Compend Contin Educ Dent 19:1034–1038, 1040-2, 1044 passim

ADA Council on Scientific Affairs (2010) Tooth whitening/bleaching: treatment considerations for dentists and their patients. http://www.ada.org/~/media/ADA/About%20the%20ADA/Files/

whitening_bleaching_treatment_considrations_for_patients_and_dentists.ashx. Accessed 14 Dec 2015
ADA Council on Scientific Affairs (2012) Statement on the safety and effectiveness of tooth whitening products. http://www.ada.org/en/about-the-ada/ada-positions-policies-and-statements/tooth-whitening-safety-and-effectiveness. Accessed 14 Dec 2015
ADA Seal Product Category (2015). http://www.ada.org/en/science-research/ada-seal-of-acceptance/ada-seal-products/product-category/?category=Whitening+Products%2c+Dentist+Dispensed%2fHome-Use. Accessed 19 Dec 2015
Al Shethri S, Matis BA, Cochran MA, Zekonis R, Stropes M (2003) A clinical evaluation of two in-office-bleaching products. Oper Dent 28:488–495
Alfonso-Prieto M, Biarnés X, Vidossich P, Rovira C (2009) The molecular mechanism of the catalase reaction. J Am Chem Soc 131:11751–11761
Almeida LC, Soares DG, Azevedo FA, Gallinari Mde O, de Souza Costa CA, Santos PH, Briso AL (2015) At-Home Bleaching: Color Alteration, Hydrogen Peroxide Diffusion and Cytotoxicity. Braz Dent J 26:378–383
American Academy of Cosmetic Dentistry (2004). http://www.aacd.com/proxy/files/Publications%20and%20Resources/Can%20a%20new%20smile%20make%20you%20appear%20more%20intelligent%20article.doc. Accessed 18 Dec 2015
American Academy of Pediatric Dentistry Council on Clinical Affairs (2015) Policy on the use of dental bleaching for child and adolescent patients. Pediat Dent 37(6 Suppl):76–78
American Association of Endodontists (2020) Glossary of endodontic terms, 10th edn. American Association of Endodontists, Chicago, IL, p 9
Amir FA, Gutmann JL, Witherspoon DE (2001) Calcific metamorphosis: a challenge in endodontic diagnosis and treatment. Quintessence Int 32:447–455
Anderson DG, Chiego DJ Jr, Glickman GN, McCauley LK (1999) A clinical assessment of the effects of 10% carbamide peroxide gel on human pulp tissue. J Endod 25:247–250
Armênio RV, Fitarelli F, Armênio MF, Demarco FF, Reis A, Loguercio AD (2008) The effect of fluoride gel use on bleaching sensitivity: a double-blind randomized controlled clinical trial. J Am Dent Assoc 139:592–597
Barghi N, Godwin JM (1994) Reducing the adverse effect of bleaching on composite-enamel bond. J Esthet Dent 6:157–161
Barros Júnior EdS, Ribeiro MES, Lima RR, Souza Júnior MHdSe, Loretto SC (2022) Excessive dental bleaching with 22% carbamide peroxide combined with erosive and abrasive challenges: new insights into the morphology and surface properties of enamel. Materials 15:7496
Basting RT, Rodrigues AL Jr, Serra MC (2005) The effect of 10% carbamide peroxide, carbopol and/or glycerin on enamel and dentin microhardness. Oper Dent 30:608–616
Basting RT, Amaral FL, França FM, Flório FM (2012) Clinical comparative study of the effectiveness of and tooth sensitivity to 10% and 20% carbamide peroxide home-use and 35% and 38% hydrogen peroxide in-office bleaching materials containing desensitizing agents. Oper Dent 37:464–473
Ben-Amar A, Liberman R, Gorfil C, Bernstein Y (1995) Effect of mouthguard bleaching on enamel surface. Am J Dent 8:29–32
Bernardon J, Sartori N, Ballarin A, Perdigao J, Lopes GC, Baratieri L (2010) Clinical performance of vital bleaching techniques. Oper Dent 35:3–10
Bitter NC (1998) A scanning electron microscopy study of the long term effect of bleaching agents on the enamel surface in vivo. Gen Dent 46:84–88
Bizhang M, Chun YH, Damerau K, Singh P, Raab WH, Zimmer S (2009) Comparative clinical study of the effectiveness of three different bleaching methods. Oper Dent 34:635–641
Bodden MK, Haywood VB (2003) Treatment of endemic fluorosis and tetracycline staining with macroabrasion and nightguard vital bleaching: a case report. Quintessence Int 34:87–91
Boushell LW, Ritter AV, Garland GE, Tiwana KK, Smith LR, Broome A, Leonard RH (2012) Nightguard vital bleaching: side effects and patient satisfaction 10 to 17 years post-treatment. J Esthet Restor Dent 24:211–219

Bowles WH, Bokmeyer TJ (1997) Staining of adult teeth by minocycline: binding of minocycline by specific proteins. J Esthet Dent 9:30–34
Bowles WH, Thompson LR (1986) Vital bleaching: The effects of heat and hydrogen peroxide on pulpal enzymes. J Endod 12:108–112
Brännström M, Lindén LA, Aström A (1967) The hydrodynamics of the dental tubule and of pulp fluid. A discussion of its significance in relation to dentinal sensitivity. Caries Res 1:310–317
Brännström M, Johnson G, Nordenvall KJ (1979) Transmission and control of dentinal pain: resin impregnation for the desensitization of dentin. J Am Dent Assoc 99:612–618
Brooks JK, Bashirelahi N, Reynolds MA (2017) Charcoal and charcoal-based dentifrices: A literature review. J Am Dent Assoc 14):661-670
Browning WD, Chan DC, Myers ML, Brackett WW, Brackett MG, Pashley DH (2008) Comparison of traditional and low sensitivity whiteners. Oper Dent 33:379–385
Buchalla W, Attin T (2007) External bleaching therapy with activation by heat, light or laser - A systematic review. Dent Mater 23:586–596
Cardenas AFM, Maran BM, Araújo LCR, de Siqueira FSF, Wambier LM, Gonzaga CC, Loguercio AD, Reis A (2019) Are combined bleaching techniques better than their sole application? A systematic review and meta-analysis. Clin Oral Investig 23:3673–3689
Cardoso PC, Reis A, Loguercio A, Vieira LC, Baratieri LN (2010) Clinical effectiveness and tooth sensitivity associated with different bleaching times for a 10 percent carbamide peroxide gel. J Am Dent Assoc 141:1213–1220
Carey CM (2014) Tooth whitening: what we now know. J Evid Based Dent Pract 14(Suppl):70–76
Carneiro TS, Favoreto MW, Bernardi LG, Sutil E, Wendlinger M, Centenaro GG, Reis A, Loguercio AD (2022) Gingival irritation in patients submitted to at-home bleaching with different cutouts of the bleaching tray: a randomized, single-blind clinical trial. Clin Oral Investig 26:4381–4390
Caro I (1980) Discoloration of the teeth related to minocycline therapy for acne. J Am Acad Dermatol 3:317–318
Cavalli V, Reis AF, Giannini M, Ambrosano GM (2001) The effect of elapsed time following bleaching on enamel bond strength of resin composite. Oper Dent 26:597–602
Cavalli V, Giannini M, Carvalho RM (2004) Effect of carbamide peroxide bleaching agents on tensile strength of human enamel. Dent Mater 20:733–739
Celik EU, Yildiz G, Yazkan B (2013) Clinical evaluation of enamel microabrasion for the aesthetic management of mild-to-severe dental fluorosis. J Esthet Restor Dent 25:422–430
Cheek CC, Heymann HO (1999) Dental and oral discolorations associated with minocycline and other tetracycline analogs. J Esthet Dent 11:43–48
Chen HP, Chang CH, Liu JK, Chuang SF, Yang JY (2008) Effect of fluoride containing bleaching agents on enamel surface properties. J Dent 36:718–725
Chng HK, Ramli HN, Yap AU, Lim CT (2005) Effect of hydrogen peroxide on intertubular dentine. J Dent 33:363–369
Christensen GJ (2003) Bleaching teeth -- which way is best? J Esthet Restor Dent 15:137–139
Cibirka RM, Myers M, Downey MC, Nelson SK, Browning WD, Hawkins IK, Dickinson GL (1999) Clinical study of tooth shade lightening from dentist-supervised, patient-applied treatment with two 10% carbamide peroxide gels. J Esthet Dent 11:325–331
Cooper JS, Bokmeyer TJ, Bowles WH (1992) Penetration of the pulp chamber by carbamide peroxide bleaching agents. J Endod 18:315–317
Cortes G, Pini NP, Lima DA, Liporoni PC, Munin E, Ambrosano GM, Aguiar FH, Lovadino JR (2013) Influence of coffee and red wine on tooth color during and after bleaching. Acta Odontol Scand 71:1475–1480
Croll TP (1990) Enamel microabrasion for removal of superficial dysmineralization and decalcification defects. J Am Dent Assoc 120:411–415
Croll TP (1994) Tooth bleaching for children and teens: a protocol and examples. Quintessence Int 25:811–817
Croll TP (1997) Enamel microabrasion: observations after 10 years. J Am Dent Assoc 128(Suppl):45S–50S

Croll TP (2009) Fluorosis. J Am Dent Assoc 140:278–279. (Comment on: J Am Dent Assoc 2008 Nov;139(11):1457–68)
Croll TP, Cavanaugh RR (1986a) Enamel color modification by controlled hydrochloric acid-pumice abrasion. I Technique and examples. Quintessence Int 17:81–87
Croll TP, Cavanaugh RR (1986b) Hydrochloric acid-pumice enamel surface abrasion for color modification: results after six months. Quintessence Int 17:335–341
Croll TP, Donly KJ (2014) Tooth bleaching in children and teens. J Esthet Restor Dent 26:147–150
Cullen SI (1978) Low-dose minocycline therapy in tetracycline-recalcitrant acne vulgaris. Cutis 21:101–104
Cutress TW, Suckling GW (1990) Differential diagnosis of dental fluorosis. J Dent Res 69 Spec No:714–720. discussion 721
Cvitko E, Denehy GE, Swift EJ Jr, Pires JA (1991) Bond strength of composite resin to enamel bleached with carbamide peroxide. J Esthet Dent 3:100–102
da Rosa G, Maran BM, Schmitt VL, Loguercio AD, Reis A, Naufel FS (2020) Effectiveness of whitening strips use compared with supervised dental bleaching: a systematic review and meta-analysis. Oper Dent 45:E289–E307
da Silva AP, de Oliveira R, Cavalli V, Arrais CA, Giannini M, de Carvalho RM (2005) Effect of peroxide-based bleaching agents on enamel ultimate tensile strength. Oper Dent 30:318–324
Dabbagh B, Alvaro E, Vu DD, Rizkallah J, Schwartz S (2002) Clinical complications in the revascularization of immature necrotic permanent teeth. Pediatr Dent 34:414–417
Davies PA, Little K, Aherne W (1962) Tetracyclines and yellow teeth. Lancet 279(7232):743
Dawson PF, Sharif MO, Smith AB, Brunton PA (2011) A clinical study comparing the efficacy and sensitivity of home vs combined whitening. Oper Dent 36:460–466
de Geus JL, Bersezio C, Urrutia J, Yamada T, Fernández E, Loguercio AD, Reis A, Kossatz S (2015a) Effectiveness of and tooth sensitivity with at-home bleaching in smokers: a multicenter clinical trial. J Am Dent Assoc 146:233–240
de Geus JL, de Lara MB, Hanzen TA, Fernández E, Loguercio AD, Kossatz S, Reis A (2015b) One-year follow-up of at-home bleaching in smokers before and after dental prophylaxis. J Dent 43:1346–1351
de Geus JL, Rezende M, Margraf LS, Bortoluzzi MC, Fernández E, Loguercio AD, Reis A, Kossatz S (2015c) Evaluation of genotoxicity and efficacy of at-home bleaching in smokers: a single-blind controlled clinical trial. Oper Dent 40:E47–E55
Del Real García JF, Saldaña-Velasco FR, Sánchez-de la Rosa SV, Ortiz-García YM, Morales-Velazquez G, Gómez-Meda BC, Zúñiga-González GM, Sánchez-Parada MG, Zamora-Perez AL (2019) In vivo evaluation of the genotoxicity and oxidative damage in individuals exposed to 10% hydrogen peroxide whitening strips. Clin Oral Investig 23:3033–3046
Deliperi S, Bardwell D, Papathanasiou A (2004) Clinical evaluation of a combined in-office and take-home bleaching system. J Am Dent Assoc 135:628–634
Deliperi S, Congiu MD, Bardwell DN (2006) Integration of composite and ceramic restorations in tetracycline-bleached teeth: a case report. J Esthet Restor Dent 18:126–134
Denehy GE, Swift EJ Jr (1992) Single-tooth home bleaching. Quintessence Int 23:595–598
Devila A, Lasta R, Zanella L, Agnol MD, Rodrigues-Junior SA (2020) Efficacy and adverse effects of whitening dentifrices compared with other products: a systematic review and meta-analysis. Oper Dent 45:E77–E90
Dodd MA, Dole EJ, Troutman WG, Bennahum DA (1998) Minocycline-associated tooth staining. Ann Pharmacother 32:887–889
Donly KJ, O'Neill M, Croll TP (1992) Enamel microabrasion: a microscopic evaluation of the "abrosion effect". Quintessence Int 23:175–179
Eachempati P, Kumbargere Nagraj S, Kiran Kumar Krishanappa S, Gupta P, Yaylali IE (2018) Home-based chemically-induced whitening (bleaching) of teeth in adults. Cochrane Database Syst Rev 12(12):CD006202
Efeoglu N, Wood DJ, Efeoglu C (2007) Thirty-five percent carbamide peroxide application causes in vitro demineralization of enamel. Dent Mater 23:900–904
Eisenberg E (1975) Anomalies of the teeth with stains and discolorations. J Prev Dent 2(7–14):16–20

Ekman P, Friesen WV, O'Sullivan M (1988) Smiles when lying. J Pers Soc Psychol 54:414–420
European Commission Scientific Committee on Consumer Products (2007) Opinion on hydrogen peroxide, in its free form or when released, in oral hygiene products and tooth whitening products. http://ec.europa.eu/health/ph_risk/committees/04_sccp/docs/sccp_o_122.pdf, Accessed 30 July 2022
European Union Council Directive 2011/84/EU of 20 September 2011. Official Journal of the European Union, 29 September 2011. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:283:0036:0038:en:PDF. Accessed 30 July 2022
Faghihian R, Shirani M, Tarrahi MJ, Zakizade M (2019) Efficacy of the Resin Infiltration Technique in Preventing Initial Caries Progression: A Systematic Review and Meta-Analysis. Pediatr Dent 41:88–94
Fejerskov O, Manji F, Baelum V (1990) The nature and mechanisms of dental fluorosis in man. J Dent Res 69:692–700
Fischer DE (1992) Method for bleaching teeth. US Patent 5098303 A. https://docs.google.com/viewer?url=patentimages.storage.googleapis.com/pdfs/US5098303.pdf. Accessed 16 Dec 2015
Fischer DE (1995) Dental bleaching compositions and methods for bleaching teeth surfaces. US Patent US5409631 A https://docs.google.com/viewer?url=patentimages.storage.googleapis.com/pdfs/US5409631.pdf. Accessed 16 Dec 2015
Franco MC, Uehara J, Meroni BM, Zuttion GS, Cenci MS (2020) The effect of a charcoal-based powder for enamel dental bleaching. Oper Dent 45:618–623
Fugaro JO, Nordahl I, Fugaro OJ, Matis BA, Mjör IA (2004) Pulp reaction to vital bleaching. Oper Dent 29:363–368
Gassner E, Sayegh FS (1968) The nature of tetracycline complex in hard tissue of bovine teeth. Arch Oral Biol 13:597–599
Gerlach RW, Gibb RD, Sagel PA (2000) A randomized clinical trial comparing a novel 5.3% hydrogen peroxide whitening strip to 10%, 15%, and 20% carbamide peroxide tray-based bleaching systems. Compend Contin Educ Dent Suppl 21:S22–S28; S42-43
Gokay O, Tuncbilek M, Ertan R (2000) Penetration of the pulp chamber by carbamide peroxide bleaching agents on teeth restored with a composite resin. J Oral Rehabil 27:428–431
Gomes I, Moura P, Gomes G, Perdigão J (2006) Localized discoloration of central incisors: a case report. Pract Proced Aesthet Dent 18:656–660
Gysi A (1900) An attempt to explain the sensitiveness of dentine. Br J Dent Sci 43:865–868
Hanks CT, Fat JC, Wataha JC, Corcoran JF (1993) Cytotoxicity and dentin permeability of carbamide peroxide and hydrogen peroxide vital bleaching materials, in vitro. J Dent Res 72:931–938
Hannig C, Weinhold HC, Becker K, Attin T (2011) Diffusion of peroxides through dentine in vitro with and without prior use of a desensitizing varnish. Clin Oral Investig 15:863–868
Harcke SJ, Rizzolo D, Harcke HT (2019) G6PD deficiency: An update. JAAPA 32:21–26
Hassel AJ, Johanning M, Grill S, Schröder J, Wahl HW, Corcodel N, Klotz AL, Rammelsberg P, Zenthöfer A (2017) Changes of tooth color in middle and old age: A longitudinal study over a decade. J Esthet Restor Dent 29:459–463
Haywood VB (1997a) Nightguard vital bleaching: current concepts and research. J Am Dent Assoc 128(suppl):19S–25S
Haywood VB (1997b) Nightguard vital bleaching. Dent Today 16:86, 88, 90–1
Haywood VB (2002) Greening of the tooth-amalgam interface during extended 10% carbamide peroxide bleaching of tetracycline-stained teeth: a case report. J Esthet Restor Dent 14:12–17
Haywood VB (2003) Frequently asked questions about bleaching. Compend Contin Educ Dent 24:324–338
Haywood VB (2005) Treating sensitivity during tooth whitening. Compend Contin Educ Dent 26(9 Suppl 3):11–20
Haywood VB, Heymann HO (1989) Nightguard vital bleaching. Quintessence Int 20:173–176
Haywood VB, Parker MH (1999) Nightguard vital bleaching beneath existing porcelain veneers: A case report. Quintessence Int 30:743–747

Haywood VB, Houck V, Heymann HO (1991) Nightguard vital bleaching: effects of varying pH solutions on enamel surface texture and color change. Quintessence Int 22:775–782
Haywood VB, Caughman WF, Frazier KB, Myers ML (2001) Tray delivery of potassium nitrate-fluoride to reduce bleaching sensitivity. Quintessence Int 32:105–109
Haywood VB, Cordero R, Gendreau L, Kotler M, LittleJoh S, Smith S, Fabyanski J, Rupp R, Fernandez PM (2005) A study of KNO3/F toothpaste as a pretreatment to bleaching. J Dent Res 84. (spec iss A), Abstract 2126
Hendrie CA, Brewer G (2012) Evidence to suggest that teeth act as human ornament displays signaling mate quality. PLoS One 7:e42178
Heyeraas KJ, Kvinnsland I (1992) Tissue pressure and blood flow in pulpal inflammation. Proc Finn Dent Soc 88(Suppl 1):393–401
Holcomb JB, Gregory WB Jr (1967) Calcific metamorphosis of the pulp: its incidence and treatment. Oral Surg Oral Med Oral Pathol 24:825–830
Horowitz HS, Driscoll WS, Meyers RJ, Heifetz SB, Kingman A (1984) A new method for assessing the prevalence of dental fluorosis - the tooth surface index of fluorosis. J Am Dent Assoc 109:37–41
Javaheri DS, Janis JN (2000) The efficacy of reservoirs in bleaching trays. Oper Dent 25:149–151
Johnston S (2013) Feeling blue? Minocycline-induced staining of the teeth, oral mucosa, sclerae and ears - a case report. Br Dent J 215:71–73
Joiner A (2006) The bleaching of teeth: A review of the literature. J Dent 34:412–419
Joiner A (2007) Review of the effects of peroxide on enamel and dentine properties. J Dent 35:889–896
Joiner A (2010) Whitening toothpastes: a review of the literature. J Dent 38(Suppl 2):e17–e24
Jordan RE, Boksman L (1984) Conservative vital bleaching treatment of discolored dentition. Compend Contin Educ Dent 5(803–5):807
Jorgensen MG, Carroll WB (2002) Incidence of tooth sensitivity after home whitening treatment. J Am Dent Assoc 133:1076–1082
Keskin C, Sariyilmaz E, KeleŞ A (2019) The effect of bleaching agents on the compressive strength of calcium silicate-based materials. Aust Endod J 45:311–316
Kihn PW, Barnes DM, Romberg E, Peterson K (2000) A clinical evaluation of 10 percent vs. 15 percent carbamide peroxide tooth-whitening agents. J Am Dent Assoc 131:1478–1484
Kim JH, Kim Y, Shin SJ, Park JW, Jung IY (2010) Tooth discoloration of immature permanent incisor associated with triple antibiotic therapy: a case report. J Endod 36:1086–1091
Kim HJ, Jang JH, Choi D, Kim J, Shim JH, Kim DS (2020) Bleaching toothpaste with two different concentrations of hydrogen peroxide: A randomized double-blinded clinical trial. J Dent 103:103508
Kirsten GA, Freire A, de Lima AA, Ignacio SA, Souza EM (2009) Effect of reservoirs on gingival inflammation after home dental bleaching. Quintessence Int 40:195–202
Kishta-Derani M, Neiva G, Yaman P, Dennison J (2007) In vitro evaluation of tooth-color change using four paint-on tooth whiteners. Oper Dent 32:394–398
Kör Whitening (2022a) How does Kör work? https://www.korwhitening.com/how-does-kor-work/. Accessed 20 Aug 2022
Kör Whitening (2022b) What you need to know about Kör whitening…. https://en.calameo.com/read/00525460761cacf71d17b. Accessed 20 Aug 2022
Kose C, Reis A, Baratieri LN, Loguercio AD (2011) Clinical effects of at-home bleaching along with desensitizing agent application. Am J Dent 24:379–382
Kothari S, Jum'ah AA, Gray AR, Lyons KM, Yap M, Brunton PA (2020) A randomized clinical trial investigating three vital tooth bleaching protocols and associated efficacy, effectiveness and participants' satisfaction. J Dent 95:103322
Kugel G (2003) Over-the-counter tooth-whitening systems. Compend Contin Educ Dent 24:376–382
Kugel G, Perry RD, Hoang E, Scherer W (1997) Effective tooth bleaching in 5 days: using a combined in-office and at-home bleaching system. Compend Contin Educ Dent 18:378–383

Lai SC, Tay FR, Cheung GS, Mak YF, Carvalho RM, Wei SH, Toledano M, Osorio R, Pashley DH (2002) Reversal of compromised bonding in bleached enamel. J Dent Res 81:477–481
LaPorta VN, Nikitakis NG, Sindler AJ, Reynolds MA (2005) Minocycline-associated intraoral soft-tissue pigmentation: clinicopathologic correlations and review. J Clin Periodontol 32:119–122
Leonard RH Jr, Haywood VB, Phillips C (1997) Risk factors for developing tooth sensitivity and gingival irritation associated with nightguard vital bleaching. Quintessence Int 28:527–534
Leonard RH Jr, Van Haywood B, Caplan DJ, Tart ND (2003) Nightguard vital bleaching of tetracycline-stained teeth: 90 months post treatment. J Esthet Restor Dent 15:142–52; discussion 153
Leonard RH Jr, Smith LR, Garland GE, Caplan DJ (2004) Desensitizing agent efficacy during whitening in an at-risk population. J Esthet Restor Dent 16:49–55; discussion 56
Li Y (2000) Peroxide-containing tooth whiteners: an update on safety. Compend Contin Educ Dent Suppl 21(28):S4–S9
Lopes GC, Bonissoni L, Baratieri LN, Vieira LC, Monteiro S Jr (2002) Effect of bleaching agents on the hardness and morphology of enamel. J Esthet Restor Dent 14:24–30
Luque-Martinez I, Reis A, Schroeder M, Muñoz MA, Loguercio AD, Masterson D, Maia LC (2016) Comparison of efficacy of tray-delivered carbamide and hydrogen peroxide for at-home bleaching: a systematic review and meta-analysis. Clin Oral Investig 20:1419–1433
Mailart MC, Dos Santos KC, Torres CRG, Borges AB (2023) Chemical behavior of 20%-22% carbamide peroxide gels in at-home bleaching: Randomized crossover in situ trial. J Esthet Restor Dent 35(2):416–422. https://doi.org/10.1111/jerd.12975. Epub ahead of print
Maran BM, Burey A, de Paris Matos T, Loguercio AD, Reis A (2018a) In-office dental bleaching with light vs. without light: A systematic review and meta-analysis. J Dent 70:1–13
Maran BM, Vochikovski L, de Andrade Hortkoff DR, Stanislawczuk R, Loguercio AD, Reis A (2018b) Tooth sensitivity with a desensitizing-containing at-home bleaching gel-a randomized triple-blind clinical trial. J Dent 72:64–70
Maran BM, Ziegelmann PK, Burey A, de Paris MT, Loguercio AD, Reis A (2019) Different light-activation systems associated with dental bleaching: a systematic review and a network meta-analysis. Clin Oral Investig 23:1499–1512
Markowitz K (2010) Pretty painful: why does tooth bleaching hurt? Med Hypotheses 74:835–840
Martini EC, Favoreto MW, de Andrade HF, Coppla FM, Loguercio AD, Reis A (2021) One-year follow-up evaluation of reservoirs in bleaching trays for at-home bleaching. J Esthet Restor Dent 33:992–998
Matis BA (2003) Tray whitening: what the evidence shows. Compend Contin Educ Dent 24:354–362
Matis BA (2004) Ask the experts – In-office bleaching. J Esthet Restor Dent 16:87–88
Matis BA, Cochran MA, Eckert G, Carlson TJ (1998) The efficacy and safety of a 10% carbamide peroxide bleaching gel. Quintessence Int 29:555–563
Matis BA, Gaiao U, Blackman D, Schultz FA, Eckert GJ (1999) In vivo degradation of bleaching gel used in whitening teeth. J Am Dent Assoc 130:227–235
Matis BA, Mousa HN, Cochran MA, Eckert GJ (2000) Clinical evaluation of bleaching agents of different concentrations. Quintessence Int 31:303–310
Matis BA, Yousef M, Cochran MA, Eckert GJ (2002) Degradation of bleaching gels in vivo as a function of tray design and carbamide peroxide concentration. Oper Dent 27:12–18
Matis BA, Wang Y, Eckert GJ, Cochran MA, Jiang T (2006) Extended bleaching of tetracycline-stained teeth: a 5-year study. Oper Dent 31:643–651
Matis BA, Cochran MA, Eckert GJ, Matis JI (2007) In vivo study of two carbamide peroxide gels with different desensitizing agents. Oper Dent 32:549–555
Matis BA, Cochran MA, Eckert G (2009a) Review of the effectiveness of various tooth whitening systems. Oper Dent 34:230–235
Matis BA, Cochran MA, Wang G, Eckert GJ (2009b) A clinical evaluation of two in-office bleaching regimens with and without tray bleaching. Oper Dent 34:142–149

Matis BA, Matis JI, Wang Y, Monteiro S, Al-Qunaian TA, Millard R (2013) Labeled vs actual concentration of bleaching agents. Oper Dent 38:334–343
Matis BA, Wang G, Matis JI, Cook NB, Eckert GJ (2015) White diet: is it necessary during tooth whitening? Oper Dent 40:235–240
Mazur M, Westland S, Ndokaj A, Nardi GM, Guerra F, Ottolenghi L (2022) In-vivo colour stability of enamel after ICON® treatment at 6 years of follow-up: A prospective single center study. J Dent 122:103943
McCracken MS, Haywood VB (1996) Demineralization effects of 10 percent carbamide peroxide. J Dent 24:395–398
McKay FS, Black GV (1916) An investigation of mottled teeth: an endemic developmental imperfection of the enamel of the teeth, heretofore unknown in the literature of Dentistry. Dent Cosmos 58:627–644
Meireles SS, Heckmann SS, Leida FL, dos Santos IS, Della Bona A, Demarco FF (2008a) Efficacy and safety of 10% and 16% carbamide peroxide tooth-whitening gels: a randomized clinical trial. Oper Dent 33:606–612
Meireles SS, Heckmann SS, Santos IS, Della Bona A, Demarco FF (2008b) A double blind randomized clinical trial of at-home tooth bleaching using two carbamide peroxide concentrations: 6-month follow-up. J Dent 36:878–884
Meireles SS, dos Santos IS, Della Bona A, Demarco FF (2009) A double-blind randomized controlled clinical trial of 10 percent versus 16 percent carbamide peroxide tooth-bleaching agents: one-year follow-up. J Am Dent Assoc 140:1109–1117
Meireles SS, Santos IS, Bona AD, Demarco FF (2010) A double-blind randomized clinical trial of two carbamide peroxide tooth bleaching agents: 2-year follow-up. J Dent 38:956–963
Menezes LL, Lima SNL, Maia-Filho EM, Fernandes ES, Mendes SJF, Gonçalves LM, Bandeca MC, Reis A, Loguercio AD, Tavarez RRJ (2021) Clinical effects of the exposure to red wine during at-home bleaching. Quintessence Int 53:48–57
Nagarkar S, Loguercio AD, Perdigão J (2022) Evidence-based fact checking for selective procedures in restorative dentistry. Clin Oral Investig 27(2):475–488
Navarra CO, Reda B, Diolosà M, Casula I, Di Lenarda R, Breschi L, Cadenaro M (2014) The effects of two 10% carbamide peroxide nightguard bleaching agents, with and without desensitizer, on enamel and sensitivity: an in vivo study. Int J Dent Hyg 12:115–120
Niat AB, Yazdi FM, Koohestanian N (2012) Effects of drying agents on bond strength of etch-and-rinse adhesive systems to enamel immediately after bleaching. J Adhes Dent 14:511–516
Oliver TL, Haywood VB (1999) Efficacy of nightguard vital bleaching technique beyond the borders of a shortened tray. J Esthet Dent 11:95–102
Opalescence Go Whitening Features (2022). https://www.opalescence.com/products/opalescence-go. Accessed 20 Aug 2022
Opalescence Patient Instructions (2018). https://www.ultradent.com/products/categories/whitening/take-home/opalescence-pf; https://assets.ctfassets.net/wfptrcrbtkd0/4HNLSj5gokkAYcE3aqgR2D/0ed311dbf17d1a8b6ab4e0f79700dcfa/Opalescence-Opalescence-PF-Patient-Kits-IFU-1006703.02.pdf. Accessed 20 Aug 2022
Özcan M, Abdin S, Sipahi C (2014) Bleaching induced tooth sensitivity: do the existing enamel craze lines increase sensitivity? A clinical study. Odontology 102:197–202
Paic M, Sener B, Schug J, Schmidlin PR (2008) Effects of microabrasion on substance loss, surface roughness, and colorimetric changes on enamel in vitro. Quintessence Int 39:517–522
Palandi SDS, Kury M, Picolo MZD, Coelho CSS, Cavalli V (2020) Effects of activated charcoal powder combined with toothpastes on enamel color change and surface properties. J Esthet Restor Dent 32:783–790
Paris S, Meyer-Lueckel H (2009) Masking of labial enamel white spot lesions by resin infiltration—a clinical report. Quintessence Int 40:713–718
Paris S, Meyer-Lueckel H, Kielbassa AM (2007) Resin infiltration of natural caries lesions. J Dent Res 86:662–666
Perdigao J (2010) Dental whitening-revisiting the myths. Northwest Dent 89(19–21):23–26

Perdigao J, Lopes MM (2006) At-home vs. in-office whitening: Effects on the enamel ultra-morphology. J Dent Res 85(Special issue A):Abst. 1949
Perdigao J, Francci C, Swift EJ Jr, Ambrose WW, Lopes M (1998) Ultra-morphological study of the interaction of dental adhesives with carbamide peroxide-bleached enamel. Am J Dent 11:291–301
Perdigao J, Dutra-Correa M, Saraceni CHC, Delazari MA, Kodama RM, Bergamini MR (2013) Clinical evaluation of 10% carbamide peroxide with different desensitizers. J Dent Res 92(Spec Iss B):Abstract 603
Poliak SC, DiGiovanna JJ, Gross EG, Gantt G, Peck GL (1985) Minocycline-associated tooth discoloration in young adults. JAMA 254:2930–2932
Price RB, Sedarous M, Hiltz GS (2000) The pH of tooth-whitening products. J Can Dent Assoc 66:421–426
Reinhardt JW, Eivins SE, Swift EJ Jr, Denehy GE (1993) A clinical study of nightguard vital bleaching. Quintessence Int 24:379–384
Rezende M, Loguercio AD, Reis A, Kossatz S (2013) Clinical effects of exposure to coffee during at-home vital bleaching. Oper Dent 38:E229–E236
Ritter AV, Leonard RH, St Georges AJ, Caplan DJ, Haywood VB (2002) Safety and stability of nightguard vital bleaching: 9 to 12 years post-treatment. J Esthet Rest Dent 14:275–285
Robinson FG, Haywood VB (2000) Bleaching and temporomandibular disorder using a half tray design: a clinical report. J Prosthet Dent 83:501–503
Robinson C, Kirkham J (1990) The effect of fluoride on the developing mineralized tissues. J Dent Res 69:685–691
Robinson C, Hallsworth AS, Weatherell JA, Künzel W (1976) Arrest and control of carious lesions: a study based on preliminary experiments with resorcinol-formaldehyde resin. J Dent Res 55:812–818
Rotstein I (1993) Role of catalase in the elimination of residual hydrogen peroxide following tooth bleaching. J Endod 19:567–569
Rotstein I, Lehr Z, Gedalia I (1992) Effect of bleaching agents on inorganic components of human dentin and cementum. J Endod 18:290–293
Salman RA, Salman DG, Glickman RS, Super S, Salman L (1985) Minocycline induced pigmentation of the oral cavity. J Oral Med 40:154–157
Sánchez AR, Rogers RS 3rd, Sheridan PJ (2004) Tetracycline and other tetracycline-derivative staining of the teeth and oral cavity. Int J Dermatol 43:709–715
Seltzer S, Bender IB, Ziontz M (1963) The dynamics of pulp inflammation: correlations between diagnostic data and actual histologic findings in the pulp. Oral Surg Oral Med Oral Pathol 16:846–871
Senestraro SV, Crowe JJ, Wang M, Vo A, Huang G, Ferracane J, Covell DA Jr (2013) Minimally invasive resin infiltration of arrested white-spot lesions: a randomized clinical trial. J Am Dent Assoc 144:997–1005
Serraglio CR, Zanella L, Dalla-Vecchia KB, Rodrigues-Junior SA (2016) Efficacy and safety of over-the-counter whitening strips as compared to home-whitening with 10% carbamide peroxide gel-systematic review of RCTs and metanalysis. Clin Oral Investig 20:1–14
Seymour RA, Heasman PA (1995) Tetracyclines in the management of periodontal diseases. A review. J Clin Periodontol 22:22–35
Shannon H, Spencer P, Gross K, Tira D (1993) Characterization of enamel exposed to 10% carbamide peroxide bleaching agents. Quintessence Int 24:39–44
Shinohara MS, Peris AR, Pimenta LA, Ambrosano GM (2005) Shear bond strength evaluation of composite resin on enamel and dentin after nonvital bleaching. J Esthet Restor Dent 17:22–29
Shwachman H, Fekete E, Kulczycki LL, Foley GE (1958–1959) The effect of long-term antibiotic therapy in patients with cystic fibrosis of the pancreas. Antibiot Annu 6:692–699
Sismanoglu S, Yildirim-Bilmez Z, Gurcan AT, Gumustas B, Taysi M, Berkman M (2022) Influence of intracoronal bleaching agents on the bond strength of MTA cements to composite resin and their surface morphology. Odontology 110:148–156

Soares DG, Ribeiro AP, Sacono NT, Coldebella CR, Hebling J, de Souza Costa CA (2011) Transenamel and transdentinal cytotoxicity of carbamide peroxide bleaching gels on odontoblast-like MDPC-23 cells. Int Endod J 44:116–125

Soares DG, Pontes EC, Ribeiro AP, Basso FG, Hebling J, Costa CA (2013) Low toxic effects of a whitening strip to cultured pulp cells. Am J Dent 26:283–285

Spyrides GM, Perdigao J, Pagani C, Araújo MA, Spyrides SM (2000) Effect of whitening agents on dentin bonding. J Esthet Dent 12:264–270

Stroner WF, Van Cura JE (1984) Pulpal dystrophic calcification. J Endod 10:202–204

Sulieman MA (2008) An overview of tooth-bleaching techniques: chemistry, safety and efficacy. Periodontol 2000 48:148–169

Sulieman M, Addy M, Macdonald E, Rees JS (2004) A safety study in vitro for the effects of an in-office bleaching system on the integrity of enamel and dentine. J Dent 32:581–590

Swift EJ Jr, May KN Jr, Wilder AD Jr, Heymann HO, Bayne SC (1999) Two-year clinical evaluation of tooth whitening using an at-home bleaching system. J Esthet Dent 11:36–42

Tam L (2001) Effect of potassium nitrate and fluoride on carbamide peroxide bleaching. Quintessence Int 32:766–770

Tam LE, Lim M, Khanna S (2005) Effect of direct peroxide bleach application to bovine dentin on flexural strength and modulus in vitro. J Dent 33:451–458

Tay LY, Kose C, Loguercio AD, Reis A (2009) Assessing the effect of a desensitizing agent used before in-office tooth bleaching. J Am Dent Assoc 140:1245–1251

Thitinanthapan W, Satamanont P, Vongsavan N (1999) In vitro penetration of the pulp chamber by three brands of carbamide peroxide. J Esthet Dent 11:259–264

Tilley BC, Alarcón GS, Heyse SP, Trentham DE, Neuner R, Kaplan DA, Clegg DO, Leisen JC, Buckley L, Cooper SM, Duncan H, Pillemer SR, Tuttleman M, Fowler SE (1995) Minocycline in rheumatoid arthritis. A 48-week, double-blind, placebo-controlled trial. MIRA Trial Group. Ann Intern Med 122:81–89

Tredwin CJ, Scully C, Bagan-Sebastian JV (2005) Drug-induced disorders of teeth. J Dent Res 84:596–602

Tsujimoto M, Ookubo A, Wada Y, Matsunaga T, Tsujimoto Y, Hayashi Y (2011) Surface changes of mineral trioxide aggregate after the application of bleaching agents: electron microscopy and an energy-dispersive X-ray microanalysis. J Endod 37:231–234

Türkün M, Kaya AD (2004) Effect of 10% sodium ascorbate on the shear bond strength of composite resin to bleached bovine enamel. J Oral Rehabil 31:1184–1191

Vaez SC, Correia A, Santana TR, Peixoto AC, Leal PC, Faria-E-Silva AL (2019) Is a single preliminary session of in-office bleaching beneficial for the effectiveness of at-home tooth bleaching? A randomized controlled clinical trial. Oper Dent 44:E180–E189

Vaidya S, Ahuja N, Bajaj P, Kapoor C, Sabarwal R, Rajpal K (2015) Objective measurement of shade color in age estimation. J Forensic Dent Sci 7:171–174

Vaz MM, Lopes LG, Cardoso PC, Souza JB, Batista AC, Costa NL, Torres ÉM, Estrela C (2016) Inflammatory response of human dental pulp to at-home and in-office tooth bleaching. J Appl Oral Sci 24:509–517

Wallman IS, Hilton HB (1962) Teeth pigmented by tetracycline. Lancet 279(7234):827–829

Wang Y, Gao J, Jiang T, Liang S, Zhou Y, Matis BA (2015) Evaluation of the efficacy of potassium nitrate and sodium fluoride as desensitizing agents during tooth bleaching treatment - A systematic review and meta-analysis. J Dent 43:913–923

Weitzman SA, Weitberg AB, Stossel TP, Schwartz J, Shklar G (1986) Effects of hydrogen peroxide on oral carcinogenesis in hamsters. J Periodontol 57:685–688

Xiao J, Zhou XD, Zhu WC, Zhang B, Li JY, Xu X (2007) The prevalence of tooth discolouration and the self-satisfaction with tooth colour in a Chinese urban population. J Oral Rehabil 34:351–360

Zegarelli EV, Denning CR, Kutscher AH, Tuoti F, di Sant'agnese PA (1960) Tooth discoloration in cystic fibrosis (letters to the Editor). Pediatrics 26:1050–1051

Zekonis R, Matis BA, Cochran MA, Al Shetri SE, Eckert GJ, Carlson TJ (2003) Clinical evaluation of in-office and at-home bleaching treatments. Oper Dent 28:114–121

In-Office Whitening: The Latest Evidence

7

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Abstract

In this chapter we will present the step-by-step procedure of in-office whitening (or in-office bleaching) and the respective efficacy and side effects. We will also address other characteristics of in-office bleaching, including the number of clinical appointments required to reach effective whitening, the concentration of the peroxide-based bleaching products, and the effects of dentin dehydration and demineralization on the outcome, as well as bleaching-induced tooth sensitivity. Some frequently asked questions (FAQ) will be answered at the end of the chapter.

7.1 Introduction

In-office whitening is a treatment option in the dental bleaching armamentarium. Not every patient is willing or able to wear tray delivery products. Some patients do not adapt well to the at-home bleaching protocol due to the required daily usage of a bleaching tray, as well as the need to wait for a few weeks to obtain satisfactory results. In some cases in-office bleaching is carried out to motivate patients prior to starting the at-home bleaching protocol as the first step of the combined or jump-start technique, as discussed in Chap. 6. This is the reason why in-office bleaching may be considered an alternative to the more traditional and safer at-home bleaching treatment. Several aspects of in-office bleaching will be discussed in this chapter to provide clinicians with a better understanding of the protocol and the particularities of the technique, besides facilitating its incorporation into the dental office daily practice.

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7.2 Efficacy

In-office whitening is performed with high concentrations of hydrogen peroxide (HP), usually ranging from 15 to 40%. A whitening effect is observed regardless of the concentration of the bleaching gel (Maran et al. 2020a; Pontes et al. 2020), as a result of HP being an active molecule that acts as a strong oxidizing agent through the formation of free radicals, reactive oxygen molecules, and HP anions (Bowles and Ugwuneri 1987).

Previous studies have claimed that the tooth shade is affected by the intrinsic organic chromophores present in the dental structure (Fuss et al. 1989; Watts and Addy 2001; Sulieman et al. 2003; Joiner 2006). Organic chromophores are colorful chemical molecules, which consist of complex molecules such as aromatic compounds or bioinorganic metallic complexes such as chelates (Eimar et al. 2012b). These chemical compounds can be easily identified with Fourier transform infrared (FTIR) and Raman spectroscopies (Eimar et al. 2012b). However, researchers have not been able to detect any of these potential chromophores (Fattibene et al. 2005; Eimar et al. 2011, 2012a). More recently, it has been suggested that HP whitens the teeth by mere oxidation of the transparent organic matrices. This process turns these matrices whiter and more opaque, which results in whiter appearance of the teeth (Kawamoto and Tsujimoto 2004; Eimar et al. 2012b).

Some particularities of in-office bleaching must be discussed. The lighter appearance of the teeth immediately after an in-office bleaching session is not only attributed to the oxidizing action of the HP into the dental organic substrate. Apart from oxidation, tooth dehydration and enamel demineralization are expected to occur. As in-office bleaching is usually performed under isolation (rubber dam or light-cured gingival barrier complemented with lip and cheek retractors), dental dehydration is always associated with the procedure. This effect is obvious when a rubber dam is used to isolate the teeth even for short periods of time (Fig. 7.1). A recent manuscript (Burki et al. 2013) demonstrated that the application of a rubber dam alone, even for a short period of 10 min, can cause a lightening effect of the teeth for a ΔE of 7.3, without any actual bleaching having occurred. Dehydration of the teeth can make them appear whiter by increasing enamel opacity. Light can no longer scatter from one hydroxyapatite crystal to another hydroxyapatite crystal (Fondriest 2003; Burki et al. 2013). Loss of translucency on dehydration causes more reflection, masking the underlying color of dentin and thus appearing lighter. This "lightened" teeth effect (by dehydration) returns to a normal color after a period of hours or days (Fig. 7.1).

Apart from dehydration, enamel demineralization results from the low pH of the majority of bleaching products currently available. Most in-office bleaching gels are delivered with a low pH because they are more stable in acidic solutions than in basic solutions. A weak acid is usually added to the solution to prevent it from decomposing when HP is stored (Chen et al. 1993), which makes the bleaching product acidic enough to cause enamel demineralization. The pH of in-office bleaching gels may vary from 2.0 to 9.0 (Price et al. 2000; Freire et al. 2009; Majeed et al. 2011; de Mendonça et al. 2021).

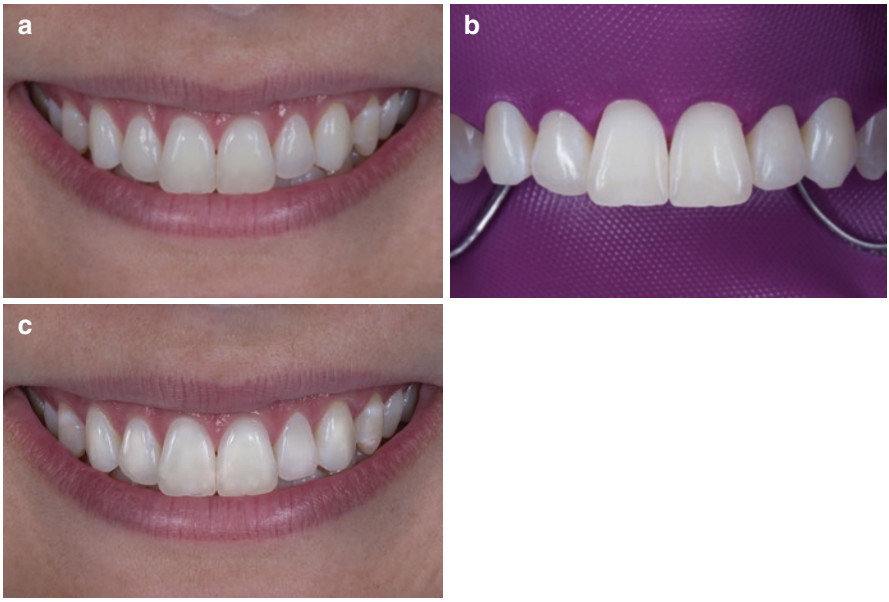

Fig. 7.1 The effect of rubber dam on lightness can be observed in these three photographs. In (**a**) patient's smile before rubber dam isolation; (**b**) the rubber dam was placed onto the maxillary arch and left undisturbed for 10 min. (**c**) The effect of dehydration is observed immediately after rubber dam removal. Images gently provided by Prof. Dr. Camilo Andrés Pulido Mora (Universidad San Francisco de Quito, Ecuador)

Taking into consideration that transient dental dehydration and demineralization occur concomitantly with the permanent effect of dental bleaching during in-office bleaching, the esthetic outcome should not be assessed immediately after the in-office bleaching session. The reliability of color measurements is questionable if carried out immediately after treatment, which has led dentists to conclude that in-office bleaching is as efficient as at-home bleaching.

The effect of color change when evaluated before complete tooth rehydration occurred in the study of Matis et al. (Matis et al. 2007). The graphic below shows the changes in L* (Fig. 7.2) and b* (Fig. 7.3) parameters after a single in-office bleaching session. In the "x" axis time 0 corresponds to the color taken immediately after in-office bleaching; the other times represent weekly measures up to 6 weeks. In general, color change (L* and b* parameters) is more pronounced when measured immediately after the procedure (time 0), with significant reductions of L* and increases of b* after 1–2 weeks due to the tooth rehydration and remineralization. Therefore, the "real" bleaching effect resulting from oxidation can only be measured 1–2 weeks after the end of the in-office bleaching session.

The difference between the "whitening outcome" observed immediately after bleaching and that measured 1 week later has been mistakenly interpreted as color rebound, with some researchers concluding that in-office bleaching is not as

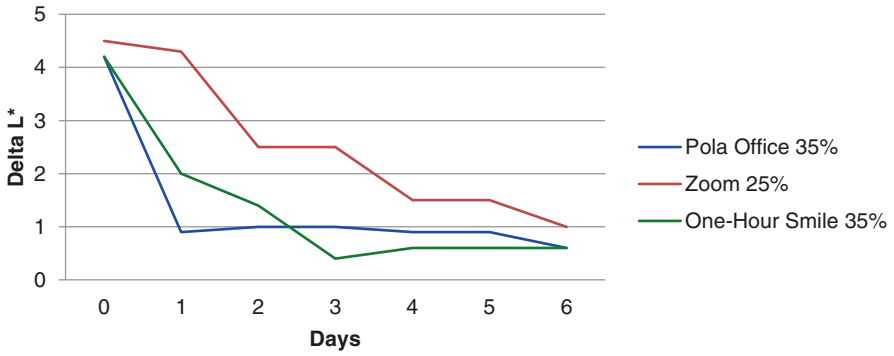

Fig. 7.2 Variation in the ΔL* in a 6-week period after a single in-office bleaching with different products. Adapted from Matis et al. (Matis et al. 2007)

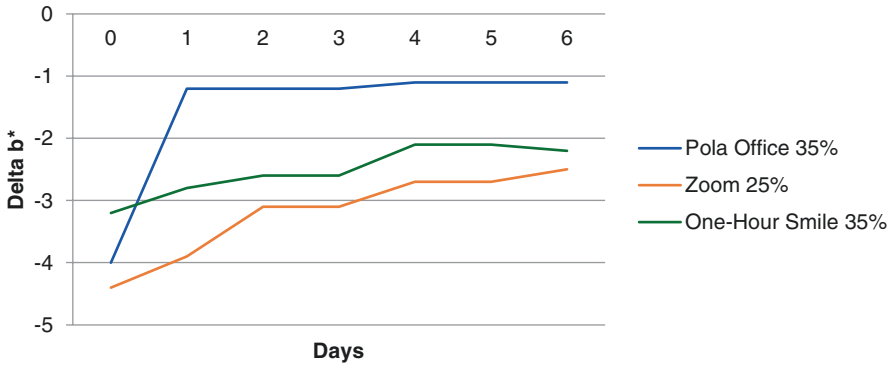

Fig. 7.3 Variation in the Δb* in a 6-week period after a single in-office bleaching with different products. Adapted from Matis et al. (Matis et al. 2007)

efficient as at-home bleaching (Matis et al. 2007). Several studies have demonstrated that 1 week of at-home bleaching with 10% or 16% carbamide peroxide gel usually results in a change of two to four shade guide units in the value-oriented Vita Classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) (Zekonis et al. 2003; Bernardon et al. 2010; Costa et al. 2010; Rezende et al. 2013). This is approximately equivalent to the change reported after a single in-office bleaching session with 35% HP gel when used for 45–60 min (Zekonis et al. 2003; Bernardon et al. 2010; Kossatz et al. 2011; Reis et al. 2011b).

There are also other factors that may explain the general belief that in-office bleaching is not effective. It is known that the whitening effect is related to the concentration, the application time, and the number of changes of the in-office bleaching gel (Dietschi et al. 2006; Joiner 2006; Matis et al. 2007). In two systematic reviews of the literature (Luque-Martinez et al. 2016; Maran et al. 2020a), we observed a high heterogeneity among studies in many issues, such as type of

materials, concentration of the products, and significant variations in in-office bleaching protocols.

Inadequate bleaching protocols will not lead to a satisfactory bleaching outcome. For instance, some studies performed only a single in-office bleaching session (da Costa et al. 2010; Giachetti et al. 2010; Moghadam et al. 2013; Pintado-Palomino et al. 2015), which is not sufficient to reach patient's satisfaction (de Silva et al. 2006; Salem and Osman 2011). At least two or three bleaching sessions may be need to reach a whitening degree similar to that of a 2- or 3-week at-home bleaching treatment (Marson et al. 2008b; Tay et al. 2009; Bernardon et al. 2010; Reis et al. 2011b, 2013; Basting et al. 2012).

Similar variation occurs with the product application time. While a 40–50-min application is related with a significant whitening outcome, there are reports of shorter application times, such as 10–20 min (Auschill et al. 2005; Giachetti et al. 2010; Mehta et al. 2013). A very recent clinical study reported that a single 15-min application of the 35% HP does not reach the same degree of whitening obtained with two and three 15-min applications of the same product (Kose et al. 2016; Meireles et al. 2021).

Some manufacturers advocate the application of their products with light activation (quartz-tungsten halogen light-curing units, LEDs, and lasers) to optimize the bleaching outcome (Ziemba et al. 2005; Kishi et al. 2011; Bortolatto et al. 2014). The benefits of light activation are rather controversial (Buchalla and Attin 2007; He et al. 2012) and seem to be useless for high-concentrated HP gels (Marson et al. 2008b; Alomari and El Daraa 2010; Kossatz et al. 2011). For low-concentrated HP gels, this light association may have some benefits (Ziemba et al. 2005; Ontiveros and Paravina 2009; Bortolatto et al. 2014). However, these expected benefits were not confirmed in several recent systematic reviews of clinical studies (He et al. 2012; Maran et al. 2018, 2019; SoutoMaior et al. 2019). This will be discussed in more detail in the section of FAQ at the end of this chapter.

This variation in the concentration of in-office bleaching in different studies makes the comparison of the in-office bleaching protocols very difficult. However, efficient whitening has been observed in studies that used 35% HP with reports of overall color change of five to eight shade guide units after two in-office bleaching sessions (Marson et al. 2008b; Tay et al. 2009; Bernardon et al. 2010; Strobl et al. 2010; Reis et al. 2011a). This wide range of color change is probably the result of the small variations in HP concentration, number of bleaching sessions, and baseline shade of the teeth of the participants in the clinical trials (Rezende et al. 2016b).

7.3 Adverse Effects

As in-office bleaching is used with high HP concentrations there are more concerns about adverse effects in comparison with at-home bleaching. The two most frequent adverse effects of in-office bleaching are bleaching-induced tooth sensitivity (TS) and gingival tissue burning.

7.3.1 Bleaching-Induced Tooth Sensitivity (TS)

While effective bleaching is reported to occur with in-office bleaching, several publications have reported that patients undergoing bleaching procedures frequently complain of painful and uncomfortable sensitivity and other discomfort in the treated teeth. Although pain in bleached teeth can be induced by cold or other stimuli, most patients complain of tingling or shooting pain (zingers) of very short duration but variable frequency (Haywood 2005; Kielbassa et al. 2015) without triggering stimuli (Markowitz 2010).

Unfortunately, TS is very frequent. The reported risk of bleaching-induced TS in clinical trials of dental bleaching is quite variable, easily exceeding 50%. A review study that evaluated the individual patient data from 11 clinical trials of bleaching treatments reported a more accurate estimate of these risks. For in-office bleaching in higher concentration (35%), the risk of TS was reported to be 62.9% (95% CI 56.9–67.3), which was not much different from that reported for 10–16% carbamide peroxide for at-home bleaching (51% with a 95% CI 41.4–60.6) (Rezende et al. 2016b). Although the risk of TS was reported to be similar, the intensity of TS was very different between the bleaching protocols. In a 0–4 pain scale, the overall mean intensity of bleaching-induced TS for in-office bleaching was 2.8 ± 2.9, while for at-home bleaching, it was 0.5 ± 0.9 (Rezende et al. 2016b). Also, two systematic reviews of clinical studies evaluated low-/medium-concentrated vs. high-concentrated in-office bleaching gels (Maran et al. 2020a; Pontes et al. 2020). One of them showed that the risk of having TS was 33% lower (on average) for low-/medium-concentrated HP compared to high-concentrated HP in-office bleaching gels (Maran et al. 2020a).

The etiology of bleaching-induced TS is not fully understood. Since the hydrodynamic theory of dentin sensitivity has been widely accepted as the explanation of dentinal sensation, some authors have used this theory to explain bleaching-induced TS (Swift 2005). However, pain during and following bleaching treatment can affect intact teeth lacking dentin exposure, which is in sharp contrast with the hydrodynamic theory (Markowitz 2010). As a result, other investigators have hypothesized that bleaching-induced TS may result from some degree of pulpal inflammation due to the higher amount of HP that reaches the pulp. It is widely known that HP can pass easily through the enamel and dentin to the pulp (Cooper et al. 1992) and cause damage to the pulp cells as seen in Chap. 5 (Costa et al. 2010). Further proof of this seapage of HP is the fact that color changes in dentin next to the pulp occur as fast as they do at the dentin-enamel junction (McCaslin et al. 1999; Haywood 2005). Pulp tissue damage is likely to result in the release of cell-derived factors, such as adenosine triphosphate (Cook and McCleskey 2002) and prostaglandins, which excite or sensitize pulpal nociceptors (Huynh and Yagiela 2003) causing the bleaching-induced TS (please refer to Chap. 5).

Several factors may affect the ability of HP to permeate the dental structures and consequently the damage produced by the bleaching gels. For instance, the amount of HP that permeates dental pulps is greater in teeth with restorations (Gokay et al. 2000; Patri et al. 2013; Parreiras et al. 2014). The depth and size of the restorations

(Parreiras et al. 2014), as well as the type of adhesive and restorative material (Gokay et al. 2000), may also play a significant role on the amount of HP penetration.

The tooth type is another important factor. Literature findings report that for the maxillary arch (Bonafe et al. 2013), the lateral incisor is the tooth that has been reported to cause most complaints of bleaching-induced TS. The thinner enamel and dentin layers of incisors compared to other teeth may facilitate the fast passage of HP to the pulp, allowing less time for the production and release of enzymes that protect against damage by HP. This is in agreement with histological studies of human pulps after in-office bleaching (Costa et al. 2010; Roderjan et al. 2015). In one study (Costa et al. 2010), the authors observed notable damage to the pulp tissue of lower incisors but not in premolars (Chap. 5).

Baseline color was strongly associated with TS in a recent study that pooled the data from 11 studies from the same research group (Rezende et al. 2016b). In other words, the darker the teeth, the lower the intensity and risk of TS. Darker teeth probably have a higher organic content to retain the HP in the enamel and dentin substrates, allowing less surplus HP to travel to the pulp tissue. Under these circumstances, it is possible that less HP comes in contact with the pulp tissue, which generates a lower TS. This, however, is an assumption yet not supported by basic research.

Several approaches have been tested to minimize the adverse side effect of TS. The administration of some medications perioperatively during in-office bleaching, such as selective anti-inflammatory drugs (etoricoxib) (de Paula et al. 2013), nonsteroidal anti-inflammatory drugs (ibuprofen) (Charakorn et al. 2009; Paula et al. 2013), antioxidants (ascorbic acid) (de Paula et al. 2014), corticosteroids (dexamethasone) (Rezende et al. 2016a), and the combination of acetaminophen/codeine (Coppla et al. 2018), was not effective to prevent the risk as well as the intensity of TS as confirmed by two recent systematic reviews of the literature (Carregosa Santana et al. 2019; Costa et al. 2020). Under peroral administration several factors such as the immune system, lymphatic drainage, urinary excretion, and morphological characteristics of the dentin substrate may modulate the amount of the medication that reaches the plasma and extracellular fluid around pulp cells, making these approaches not effective.

The most effective measures to minimize TS were through the application of topical desensitizers (Wang et al. 2015; Martini et al. 2021). The preoperative application of a gel composed of 5% potassium nitrate and 2% sodium fluoride for 10 min was capable of reducing the risk of TS by half, as well as the intensity of TS (Tay et al. 2009).

The effect of fluoride in this process is not clear, and the desensitizing effect of the association of sodium fluoride and potassium nitrate seems to be more related to the presence of potassium nitrate. This substance penetrates the enamel and dentin to travel to the pulp where it creates a calming effect on the nerve by affecting the transmission of nerve impulses (Ajcharanukul et al. 2007). After the nerve depolarizes in the pain stimulus response, it cannot repolarize, so the excitability of the nerve is reduced. Potassium nitrate has almost an anesthetic effect on the nerve (Haywood 2005).

Regarding the action of fluorides, it is hypothesized that the precipitation of calcium fluoride crystals in dentin can reduce the functional radius of the dentinal tubules and the permeability of this tissue to the hydrogen peroxide. By doing so, less hydrogen peroxide reaches the pulp chamber reducing the tooth sensitivity. This is yet to be confirmed, as this process seems to occur only when there are exposed dentin surfaces.

Another option is to use Gluma Desensitizer (Kulzer, Wehrheim, Germany), composed of 5 wt% glutaraldehyde and 35% weight% HEMA (Baba et al. 2002; Qin et al. 2006). Due to the low molecular weight of glutaraldehyde (molar mass 100 g/moL) and HEMA (molar mass 130 g/moL), Gluma Desensitizer may penetrate through enamel and dentin along the same pathway as the peroxide radicals. On the way to the pulp, glutaraldehyde might react by cross-linking with enamel matrix proteins and with proteins in the dentin tubular liquid (Bedran-Russo et al. 2014), thus reducing easy passage of the HP radicals to the pulp. One study showed that previous desensitization with Gluma Desensitizer for 1 min significantly reduced TS during and after whitening compared with a placebo pre-treatment (Mehta et al. 2013). In another clinical study, no significant reduction of risk and intensity of TS was observed (Diniz et al. 2018).

Although some opinion leaders claim that application of desensitizer gels composed of 5% potassium nitrate and 2% sodium fluoride prior to in-office bleaching affects the bleaching efficacy, this was not confirmed by two recent meta-analyses of the literature (Wang et al. 2015; Martini et al. 2021), most likely because the desensitizing gels used are transparent.

7.3.2 Gingival Tissue Irritation

As long as adequate protection of the gingival tissues is used through the application of a light-cured gingival barrier or rubber dam isolation, gingival burning (Fig. 7.4) is not likely to occur. This is usually not reported in clinical trials of in-office bleaching and reflects the clinical experience of the study authors. As seen in Chap. 4, in case tissue burning occurs the dental professional should apply a drop of

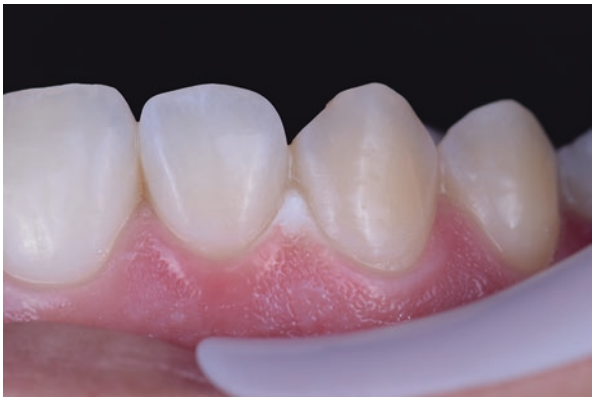

Fig. 7.4 Chemical burning of the cervical gingiva of several teeth after an in-office bleaching application with a high-concentration hydrogen peroxide

catalase and/or sodium bicarbonate (usually provided by the manufacturer) on the ulcerated lesion to mitigate the burning effect. No other measure is usually required; but in case the patient feels discomfort, a corticosteroid-based ointment may be prescribed to relieve pain.

7.4 Treatment Regimen with Step-by-Step Procedures

As mentioned earlier, in-office bleaching protocols vary significantly in clinical reports. The application time of the bleaching gel, the number of bleaching sessions, whether the protocol is associated with light, and the number of product replenishments on the dental surface are some examples.

In the present chapter, we will describe all the steps involved in an effective bleaching protocol and report some of the variations of each step as long as they can still result in an effective whitening outcome. This section will be described in steps for didactic reasons.

7.4.1 Deciding About In-Office Bleaching Gels

There are many in-office bleaching products on the dental market, which makes the choice quite difficult. They vary in the active concentration of HP, which ranges usually from 15 to 40%, and in terms of pH (Freire et al. 2009; Price et al. 2000; Majeed et al. 2011). There are some products that contain other additives such as calcium gluconate and calcium phosphates (Favoreto et al. 2023) and desensitizing agents (sodium fluoride, potassium nitrate). These systems also vary in their mode of application: most of them require product replenishment during a single in-office session, while for some products, a single 40–50-min application is required.

Several interesting studies reporting the comparison of these systems both in terms of effectiveness and side effects have been recently published, including two systematic reviews and meta-analyses comparing low- (lower than 15%) vs. high-concentrated hydrogen peroxide gel. The results showed that in-office bleaching with lower concentrations of hydrogen peroxide resulted in less tooth sensitivity and similar bleaching pattern when compared to high-concentrated hydrogen peroxide gel (Maran et al. 2020a; Pontes et al. 2020). Unfortunately, only a few low-concentrated hydrogen peroxide gels are available commercially.

As previously mentioned, whitening products should have a relatively alkaline pH to minimize potential damage, but there is a wide pH variation among in-office bleaching gels (Price et al. 2000; Freire et al. 2009; Majeed et al. 2011). This variation could be the result of the different formulations used by each manufacturer. In fact, bleaching agents contain stabilizers and other inorganic components that allow them to be stored for prolonged periods. In-office bleaching gels are delivered in low pH because they are more stable in acidic solutions than in basic solutions. When the HP gel is manufactured, a weak acid is usually added to the solution to prevent it from decomposing (Chen et al. 1993).

Some investigators have reported that the HP delivered in an alkaline medium increases the effectiveness of bleaching in the wool industry. This effectiveness is explained by the fact that the dissociation constant of the HP is about 11.5. In fact, the findings of one study showed that for a pH = 9.0, the dissociation rate of the HP was 2.7 times higher than when in an acidic solution (pH = 4.4) (Frysh et al. 1995). This finding was recently confirmed by Torres et al. (Torres et al. 2014) who observed in vitro that the efficacy of HP bleaching is directly proportional to the increase of the pH of the bleaching gel. These variations, however, did not seem to produce differences in tooth bleaching effectiveness when products with acidic and alkaline pH were compared, although a significant decrease of tooth sensitivity has been shown for alkaline gels (Kossatz et al. 2012; Loguercio et al. 2017).

Additionally, it is worth mentioning that alkaline gels usually show more stable pH during application than acidic gels (Marson et al. 2008a; Balladares et al. 2019; de Mendonça et al. 2021), which allows them to be applied in a single application without the need for several product replenishments (Reis et al. 2011a,b; Kossatz et al. 2012; Martins et al. 2018).

Although it is biologically plausible to select bleaching products that contain desensitizer or remineralizing agents, including potassium nitrate and calcium-based compounds, the effectiveness of desensitizing agents in bleaching products is still under debate. Regarding the incorporation of potassium nitrate in in-office bleaching gels, a single study that compared the color change and bleaching-induced TS of bleaching products containing potassium nitrate reported only a significant difference in the intensity of TS, but no difference in the bleaching efficacy (Maran et al. 2020b). In regard to calcium-based compounds added to bleaching gels, some promising results were obtained (Basting et al. 2012; Kossatz et al. 2012; Loguercio et al. 2015). In addition, a recent systematic review and meta-analysis partially confirmed these findings (Favoreto et al. 2023). This issue will be discussed later in this chapter.

In light of the recent evidence, we recommend the use of 35% HP alkaline gels that contain desensitizing agents. As it will be addressed in the FAQ section, a reduced concentration of HP can be used in the combined or jump-start technique. In regard to the presence of desensitizing agents we still recommend bleaching products containing those agents. The lack of evidence that desensitizing-containing gels can reduce TS cannot be interpreted as evidence of the absence of an effect. These studies are usually low powered, and we cannot rule out the fact that desensitizing-containing gels may provide some beneficial effect. We may keep using these products until high-powered clinical studies are available, as desensitizing-containing gels do not have any known detrimental effect. Finally, products should be applied according to the respective manufacturer's instructions.

7.4.2 Determination of the Baseline Tooth Color

This procedure allows the dentist and the patient to monitor color change during the bleaching protocol (Fig. 7.5). Patients usually get used very quickly with the new tooth color and may not remember which color their teeth were before protocol.

This is even more important when both dental arches are bleached simultaneously. Shade recording can be performed with a value-oriented or bleach shade guide (Fig. 7.5) and spectrophotometer, or by means of dental photographs.

Some authors encourage whitening one dental arch at a time (Haywood 2005), because it minimizes TS, allows the patient to monitor the opposing arch to compare progress, and also encourages compliance. However, this procedure significantly increases the cost of the bleaching protocol, as it requires more dental visits.

Another advantage of color recording is that baseline dental color can predict the whitening degree obtained after dental bleaching. A recent multivariable regression analysis (Rezende et al. 2016c) identified a significant relationship between baseline color and age in relation to color change estimates. After adjustment for the other variables, every increase of one shade guide unit (in the value-oriented Vita Classical A1–D4 shade guide) in the baseline color resulted in an increase of approximately 0.66 in the final color change in ΔSGU and 2.48 for the ΔE, meaning that the darker the baseline tooth color, the higher the degree of whitening. In an opposite trend, the degree of whitening is negatively affected by the patient's age (Rezende et al. 2016c). It is note worthy that the ΔEab value higher than 2.4 units exceeds the 50:50% perceptibility threshold for ΔEab, although it is still lower than the 50:50% acceptability threshold. Nevertheless, the difference would still be clinically acceptable for 50% of the observers (Paravina et al. 2015).

This allows for the dentist to manage the patient's expectations regarding the bleaching outcomes. Older patients with lighter baseline color may request more than two bleaching sessions to achieve the same whitening degree than younger patients with darker baseline dental color. It is important to perform a dental prophylaxis recording the baseline tooth color. A published paper showed a significant difference (average of two ΔE units of change) on tooth color when measured before and after dental prophylaxis (de Geus et al. 2015). This value is still lower than the 50% acceptability threshold (Paravina et al. 2015). However, this 50:50% acceptability may reach the threshold for clinical detection (ΔEab = 3.0) in some patients (de Geus et al. 2015).

Fig. 7.5 The baseline tooth color being recorded with a value-oriented shade guide after performing a dental prophylaxis

7.4.3 Application of a Desensitizing Agent

As reported earlier, one of the main side effects of in-office dental bleaching is TS. Although this side effect cannot be completely eliminated, the number of patients that experience TS and the intensity of TS can be reduced by previous application of a desensitizing gel composed of 5% potassium nitrate (Tay et al. 2009; Wang et al. 2015; Martini et al. 2021).

This procedure can be performed before or after isolation of the dental arch, as the material is not aggressive to the gingival tissue. However, as the gel is usually agitated with the aid of a rotating brush, it is recommended to apply the desensitizer before the protection of the soft tissues. The buccal surface of all the teeth to be bleached should be covered with a 1 mm-thick layer of the desensitizer and left in place for at least 10 min (Fig. 7.6). At the end of this period, the product should be agitated in each dental surface for 20 s with a rotating brush before removal. The inclusion of this step into the in-office bleaching protocol does not jeopardize the whitening efficacy of the hydrogen peroxide (Tay et al. 2009). After this period, the product should be removed with gauze (Fig. 7.7) or with a saliva ejector before

Fig. 7.6 Application of a desensitizing gel composed of 5% potassium nitrate for 10 min (Desensibilize KF 2%, FGM Dental Group, Fort Lauderdale, FL, USA). After this period the product should be agitated in each dental surface for 20 s with a rotating brush before removal

Fig. 7.7 Removal of the desensitizing gel with dental gauze or high-speed suction. Rinsing with water was performed after removing the excesses

application of the in-office bleaching gel. Rinsing can be performed as a final step for the complete removal of the product.

7.4.4 Protection of the Soft Tissues

Hydrogen peroxide in high concentrations, such as those used for in-office bleaching, may cause burning of the dental tissues (Fig. 7.4). Several attempts should be made to avoid contact with the soft tissues.

The use of lip-and-cheek retractors associated with a light-cured gingival barrier (Fig. 7.8) is quite common. The former can maintain the lips, the cheeks, and even the tongue away from the bleaching gel, while the latter prevents the contact of the bleaching gel with the gingival tissue. An increased frequency of micronuclei of cells from the gingival tissue (which is an evidence of genotoxicity) was observed in patients submitted to in-office bleaching (Klaric et al. 2013), which may be the results of soft burning or even the contact with the gingival barrier. To avoid this undesirable side effect, the gingival barrier should be adequately light-cured (Fig. 7.8) according to the respective manufacturer's recommendations, and clinicians should carefully observe the teeth from an incisal aspect to detect any sealing failure of the barrier on the gingival tissue.

Rubber dam isolation can also be used for protection of the soft tissues. However, a thick layer of petroleum jelly should be applied on the gingival tissue of the teeth to be bleached prior to inserting the rubber dam. Due to the hydrophobic nature of the petroleum jelly, the bleaching gel will be prevented from contacting the gingival tissue even if eventual isolation failure occurs.

7.4.5 Application of the In-Office Bleaching Gel

The manufacturer's instructions of the in-office bleaching gel should be followed (Figs. 7.9 and 7.10). Variations to the protocol advocated by manufacturers may

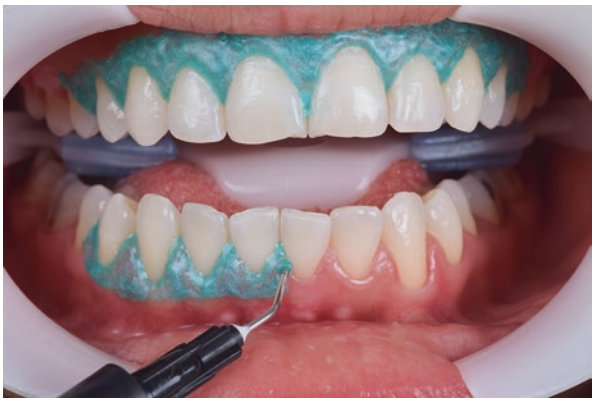

Fig. 7.8 A lip-and-cheek retractor (Arcflex, FGM Dental Group, Fort Lauderdale, FL, USA) is applied followed by the application of a light-cured gingival barrier (Top Dam, FGM Dental Group, Fort Lauderdale, FL, USA) to protect the marginal gingival tissue

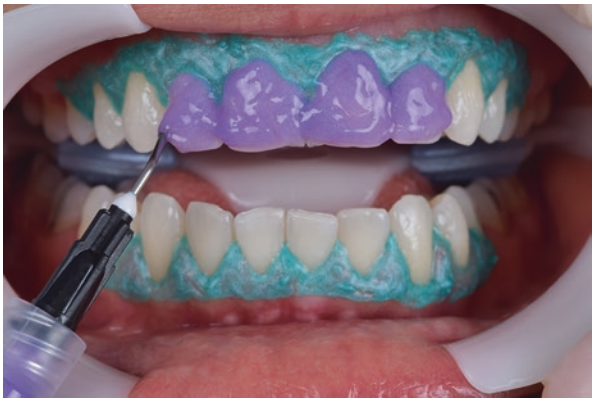

Fig. 7.9 The 35% hydrogen peroxide in-office bleaching gel (Whiteness HP Blue 35%, FGM, Joinville, SC, Brazil) is mixed and applied to all the teeth to be bleached

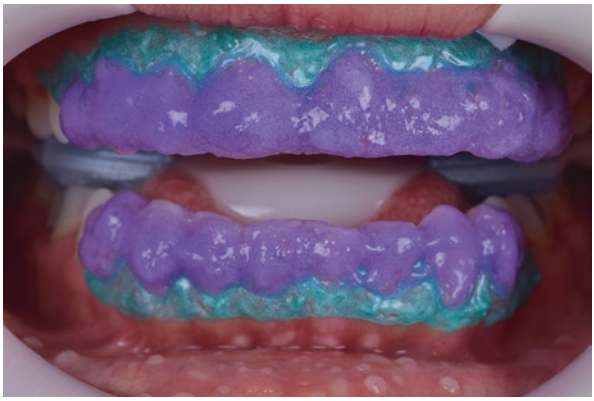

Fig. 7.10 After 5 min in place, bubbles are visible within the gel, which result from the decomposition of the hydrogen peroxide

lead to either whitening at reduced speed or increased TS rates (Reis et al. 2011b; Kose et al. 2016; Meireles et al. 2021). By increasing the number and/or time of application, one may increase the degree of whitening obtained, but at the same time the risk of TS is also increased. In an opposite trend, reducing the number and/or time of application reduces the probability of TS but also limits the degree of whitening. The increased formation of bubbles on the surface layer of in-office bleaching gel has led some manufacturers and clinicians to believe that agitation of the in-office bleaching gel with a microbrush is needed to bring fresh bleaching gel into contact with the tooth surface (Fig. 7.10). However, this agitation seems to be unnecessary because no improvement in bleaching efficacy was observed (Kiyuna et al. 2021).

Most in-office bleaching gels require replenishing the product during the clinical application period. Some gels require two, three, or four product replenishments during each clinical session. Some products, however, are indicated for a single 40–50-min application without replenishments. These products usually possess a basic pH that allows them to be used for longer application times without increasing

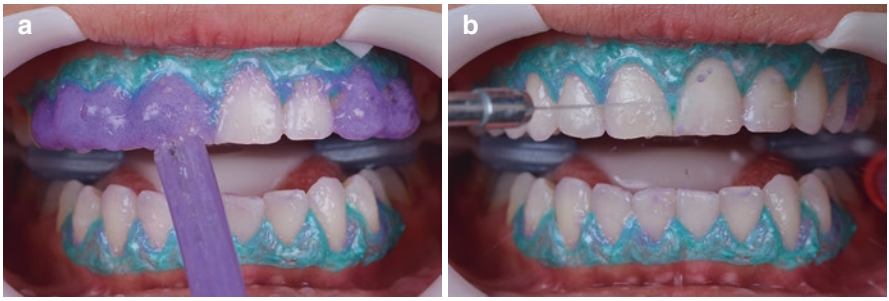

Fig. 7.11 (**a**) The suction tip was first used to remove the gel prior to (**b**) water rinsing of the tooth surfaces

the risk of TS (Kossatz et al. 2012; Reis et al. 2013). The product should be firstly removed with a cotton pellet, gauze, or high-speed suction (Fig. 7.11) before rinsing the tooth surfaces with water. This method prevents any kind of soft tissue burning.

A clinical trial evaluated the impact of changing the bleaching protocol of a high concentration (35%) in-office bleaching product. Instead of performing three 15-min applications as suggested by the manufacturer, the gel was left for 45 min without replenishment. A reduction of the bleaching speed and increase in the TS intensity was observed, most likely as a result of the slow but significant reduction of the pH of the product throughout the 45-min application (Reis et al. 2011b).

As discussed in more details in the FAQ section, some manufacturers recommend the application of their products with light activation (quartz-tungsten halogen light-curing units, LEDs, or lasers) to allegedly optimize the bleaching outcome (Ziemba et al. 2005; Kishi et al. 2011; Bortolatto et al. 2014). Several systematic reviews of the literature have concluded that light increases the risk of TS during in-office bleaching. In addition, light may not improve the bleaching efficacy when high concentrations of HP (25–35%) are used. Therefore, dentists should use the light-activated system with great caution or avoid its use altogether (He et al. 2012). One of the systematic reviews indicated that no significant benefits of such association were observed even when low-concentrated HP gels were used (Maran et al. 2018). For low-concentrated HP gels, the use of light may have some benefits. However, this association still warrants further evaluation (Ziemba et al. 2005; Ontiveros and Paravina 2009; Bortolatto et al. 2014), which will be discussed in more detail in the FAQ section.

A single in-office bleaching session is usually not enough to reach the patient's satisfaction (de Silva et al. 2006; Salem and Osman 2011). Studies that demonstrated that in-office bleaching is as effective as at-home bleaching usually performed two to three in-office bleaching sessions. Because in-office whitening often takes more than one appointment to achieve the desired whitening, appointments generally are scheduled at least 1 week apart to allow the discomfort to dissipate. However, this procedure is purely based on anecdotal evidence.

Several clinical studies from our research group indicated that the TS induced by in-office whitening only causes complaints during the initial 48 h post-bleaching.

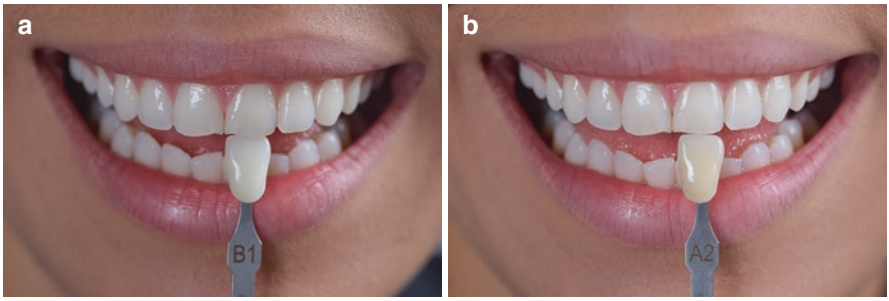

Fig. 7.12 One week after the second in-office bleaching session, the color of the patient's teeth was checked. In (**a**) one can observe that the patient's teeth reached shade B1 (the lightest shade in the value-oriented Vita Classical shade guide), which is five shades lighter than the baseline A2 shade measured at the beginning of the treatment (**b**)

Also, a randomized clinical trial revealed that a two-day interval between two in-office bleaching sessions did not increase the risk and intensity of bleaching-induced TS (de Paula et al. 2015). However, this clinical trial used a calcium-containing alkaline gel applied for a single 40-min application without replenishment (de Paula et al. 2015), which precludes any generalization of this protocol to all in-office bleaching gels currently available.

In the clinical case (Figs. 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, and 7.12), two clinical appointments were required to reach patient satisfaction. The color reached after the end of the bleaching procedure should be recorded with the same instrument used to record the baseline color. This measurement, however, should be carried out 4–7 days after the last in-office bleaching session to avoid the effects of dehydration and demineralization on the final outcomes (Fig. 7.12).

7.5 Durability of Color Change and Need for Touch-Up

As explained earlier in this chapter, the very short color reversal that occurs within some days after the in-office bleaching session cannot be interpreted as lack of effectiveness of the in-office bleaching protocol. To avoid any potential patient's frustration with the treatment, we need to instruct patients that a slight darkening is expected to occur within the next few days as a result of tooth rehydration and remineralization, which does not necessarily mean that the bleaching was unsuccessful. An adequate measurement of the baseline tooth shade will allow the dental professional to monitor the degree of color change resulting from the oxidizing nature of the hydrogen peroxide gel.

Although there are many randomized clinical trials reporting the immediate effects of several bleaching techniques, only few of them evaluated the long-term efficacy of in-office bleaching (Giachetti et al. 2010; Mondelli et al. 2012; Tay et al. 2012). These studies reported that in-office bleaching achieves stable results in periods ranging from 9 months to 2 years (Giachetti et al. 2010; Tay et al. 2012).

On the other hand, we may expect teeth to darken over longer periods of time. As the teeth age, there is a continuous deposition of secondary dentin by the pulp and increased enamel wear. Both factors increase the yellowish appearance of the teeth. Additionally, we cannot rule out the effect of staining produced by beverages and food (Meireles et al. 2010). Although these stainings are of extrinsic origin, and therefore easily removed by prophylaxis, they may affect the patient's overall perception of whiter teeth.

Based on the aforementioned explanations, touch-up bleaching may be performed whenever color rebound is detected. Specific protocols and products were discussed in Chap. 6. Another option is to apply a new single in-office bleaching session, which may achieve satisfactory results. The literature, however, lacks randomized clinical trials on this topic.

7.6 Frequently Asked Questions (FAQ)

7.6.1 Do We Need Lights to Activate Peroxidases?

As heat and light can accelerate the dissociation of hydrogen peroxide (Ontiveros 2011), both methods have been associated with in-office bleaching as early as 1918 (Abbot 1918). However, as already mentioned earlier in this chapter, several clinical trials (Marson et al. 2008b; Alomari and El Daraa 2010; Kossatz et al. 2011), and more recently several systematic revisions of the literature (He et al. 2012; Maran et al. 2018, 2019; SoutoMaior et al. 2019), point out that there is no advantage of associating heat and light with high concentrations of HP gels.

Apparently, this seems to be contradictory. In fact, from basic chemistry the highest concentration of reactants raises collisions per unit time and hence increases the reaction rate. However, if the reaction is complex and involves a series of consecutive steps, there might be a limit to which the increased concentration leads to faster reaction rates. We hypothesize that 35% HP (or higher concentration) when applied alone is able to produce enough free radicals for oxidizing the organic component of dentin, and thus, the increase in free radicals triggered by the light activation might be useless. Consequently, the further increase in HP radicals from light activation does not lead to faster bleaching due to the unknown rate of the oxidation of HP.

However, this may not be the case when using low-HP gels. Randomized clinical trials that evaluated the effect of light associated with low HP concentrations seem to show a faster whitening rate (Tavares et al. 2003; Ontiveros and Paravina 2009). For these gels it seems that the limiting factor of the oxidizing reaction rate was the amount of free radicals, and thus the association with light, which likely increases the amount of free radicals, may produce a faster reaction rate and a whitening degree similar to that of the 35% HP gel associated or not with light (He et al. 2012; Bortolatto et al. 2014). This mechanism has not been confirmed in a recent systematic review of clinical studies that evaluated the effect of different light units associated with low-concentrated bleaching gels. There were no significant improvements in the whitening effect (Maran et al. 2019).

7.6.2 Are Light-Activated Peroxides Available?

Some manufacturers indicate that their products contain orange-red color of carotene as colorants and that these compounds can be considered as activators because they are absorbed primarily at wavelengths of blue lights. If the bleaching agent absorbs the light energy of this wavelength, it heats and thus decomposes (Ontiveros 2011). Unfortunately, a literature review indicated that although the temperature of the carotene-containing bleaching gel can increase considerably, this increase was not high enough to accelerate HP decomposition significantly (Buchalla and Attin 2007).

Another option is the addition of some metals to enhance the oxidizing power of the HP, such as ferrous compounds or titanium dioxide. The photolysis of HP associated with these compounds needs to be activated by a very specific wavelength, which depends on the metals included (Ziemba et al. 2005; Kishi et al. 2011; Ontiveros 2011; Bortolatto et al. 2014). For instance, one manufacturer combined iron with a low-concentrated HP formulation. In the presence of ferrous compounds, HP can be combined with iron known as Fenton reagent. When iron reacts (with or without UV radiation), the process is renewed, and the redox reaction is further fueled (Ontiveros 2011). This is the reason why products that contain ferrous components recommend light activation with ultraviolet lights (Kugel et al. 2009; Ontiveros and Paravina 2009). The use of UV lamps requires caution. Patients, dentists, and dental assistants should wear special protection because of the known damage that ultraviolet radiation can cause to the skin. It should be mentioned that the Fenton reaction occurs with or without ultraviolet light activation. Future studies may need to focus on the evaluation of the bleaching efficacy of these bleaching systems without the use of UV lights.

Some low-concentrated HP gels (6–15%) containing semiconductors of titanium oxide nanoparticles doped with nitrogen have shown good bleaching efficacy comparable to that of 35% HP gels (Bortolatto et al. 2014; Martin et al. 2015). When exposed to blue light (LED/laser device), these nanoparticles catalyze the formation of hydroxyl radicals from HP (Sakai et al. 2007). As these titanium oxide-bleaching formulations can be used with visible lights, they are safer than the previous formulations that recommend UV light activation.

7.6.3 Manufacturers Recommend Several Consecutive Applications of In-Office Whitening Gel: How Many Applications Are Needed? For How Long?

Clinicians should follow the manufacturers' instructions for application of in-office bleaching gels. Some products must be refreshed two to four times in a 40–50-min clinical session, while other products must be left undisturbed for the whole period on the tooth surface. It is suggested that acidic gels and those that do show reduction of the pH overtime should be replenished; alkaline gels that keep the pH alkaline during application can be left on the surface for the whole application period.

However, this protocol can be changed based on the patient's profile. In case the professionals are dealing with a patient with very sensitive teeth, the frequency of product replenishments should be decreased. In addition, the application time can be reduced. This may reduce the risk and intensity of TS (Kose et al. 2016; Meireles et al. 2021) but will also require more applications to reach patient's satisfaction.

Two to three in-office bleaching sessions using 35% HP are usually required to achieve a significant color change (Marson et al. 2008b; Tay et al. 2009; Bernardon et al. 2010; Strobl et al. 2010; Reis et al. 2011a), but unfortunately this may vary depending on the baseline color of the subject's teeth in clinical trials (Rezende et al. 2016c).

7.6.4 Are Calcium Phosphate- and Fluoride-Containing Gels Effective in Decreasing Tooth Sensitivity Caused by In-Office Bleaching?

As previously mentioned, there are numerous studies that reported microstructural changes of the enamel surface induced by in-office bleaching agents (Dahl and Pallesen 2003), which results from the low pH of most bleaching products available in the market. Also, clinicians believe that these superficial alterations of the enamel surface increase TS induced by in-office gels, primarily because the surface becomes more porous to HP. This had led different clinicians to evaluate whether the preoperative application of remineralizing agents (Loguercio et al. 2015), or the addition of remineralizing products (fluoride, calcium phosphate compounds, etc.) to in-office bleaching formulations (Basting et al. 2012; Kossatz et al. 2012) might have an impact on the reduction of bleaching-induced TS. These studies failed to find a reduction in the bleaching-induced TS, which was also confirmed in a recent systematic review of clinical studies (Favoreto et al. 2023). However, in this systematic review the topical application of several remineralizing agents before or after in-office bleaching showed a significant reduction of the intensity of TS (Favoreto et al. 2023). Furthermore, no detrimental effect on the whitening efficiency was detected (Basting et al. 2012; Kossatz et al. 2012; Loguercio et al. 2015).

Actually, a previous literature review that investigated the impact of bleaching procedures on enamel surface indicated that these adverse effects on enamel are minimal. Laboratory studies that simulate the intraoral conditions as closely as possible have reported that as soon as bleached enamel comes in contact with saliva, remineralization occurs within a few days without adverse effects (Attin et al. 2009). This was also confirmed when in-office gels were used in vivo after prolonged and repeated applications (Spalding et al. 2003; Cadenaro et al. 2008, 2010).

7.6.5 Why Are Some In-Office Whitening Products Referred to as "Chemically Activated"?

As previously described, in-office gels are more stable in acidic solutions than in alkaline solutions (Chen et al. 1993). As a result, most bleaching gels are presented

in two syringes/bottles. One contains the HP product, while the other contains colorants, thickening agent, among other components.

When the contents of both syringes/bottles are mixed, a "chemical activation" occurs which increases HP decomposition making the in-office gels ready to use. This has led to erroneous interpretation that in-office gels are "chemically activated." In fact the main function of the activating gel component (synonymously referred to as "catalyst" or "booster") is to increase the pH of the mixed gel to achieve an alkaline pH close to the pKa of hydrogen peroxide (pKa = 11.0), thereby increasing the decomposition rate of peroxide and the formation of oxidative radicals (Buchalla and Attin 2007).

7.6.6 Does the "Jump-Start" Technique Improve the Final Result of a Whitening Treatment?

As indicated in the item *7.1* from this chapter, there are several factors that may explain the clinician's belief that in-office bleaching is not efficient when compared to at-home bleaching. Thus, the combination of in-office and at-home bleaching ("combined bleaching technique") has been suggested by some clinicians as a way to potentiate the bleaching effect and improve color stability (Kugel et al. 1997; Deliperi et al. 2004; Matis et al. 2009; Bernardon et al. 2010). A recent systematic review of clinical studies found no significant differences in terms of color change when combined bleaching was compared to only in-office bleaching, although a higher level of TS was observed for the group when combined bleaching was compared to only at-home bleaching (Cardenas et al. 2019).

However, considering that both bleaching techniques (in-office and at-home techniques) are effective, the main advantage of the "jump-start" technique is when some patients demand for a faster way of bleaching (Matis et al. 2009; Bernardon et al. 2010). This led to the term "jump-start" technique, which is commonly used to motivate patients to comply with the at-home bleaching protocol.

The in-office bleaching is applied before starting the at-home protocol. Nevertheless, the in-office bleaching component can be incorporated at any moment, specifically if the outcome of the at-home bleaching treatment is not as expected. The number of in-office bleaching sessions associated with the at-home procedure will be dictated by the patients' demand and the whitening response to the procedure.

Clinical studies that evaluated the combined or jump bleaching technique have used high hydrogen peroxide concentrations for the in-office phase (Kugel et al. 1997; Deliperi et al. 2004; Matis et al. 2009; Bernardon et al. 2010). This means that high levels of bleaching-induced TS were reported (Kugel et al. 1997; Deliperi et al. 2004; Matis et al. 2009; Bernardon et al. 2010).

More recently, a clinical study that compared a low and a high concentration of HP combined with 10% carbamide peroxide for at-home bleaching showed both protocols yielded the same whitening effect. The constant delivery of the at-home bleaching gel for 2 weeks after the in-office bleaching treatment might have compensated for the lower HP concentration of the in-office gel. However, the use of the

low HP concentration for the in-office phase of the bleaching protocol reduced the risk and intensity of bleaching-induced TS (Rezende et al. 2016b; Vochikovski et al. 2022).

References

Abbot CH (1918) Bleaching discolored teeth by means of 30% perhydrol and the electric light rays. J Allied Dent Soc 13:259

Ajcharanukul O, Kraivaphan P, Wanachantararak S, Vongsavan N, Matthews B (2007) Effects of potassium ions on dentine sensitivity in man. Arch Oral Biol 52:632–639

Alomari Q, El Daraa E (2010) A randomized clinical trial of in-office dental bleaching with or without light activation. J Contemp Dent Pract 11:E017–E024

Attin T, Schmidlin PR, Wegehaupt F, Wiegand A (2009) Influence of study design on the impact of bleaching agents on dental enamel microhardness: a review. Dent Mater 25:143–157

Auschill TM, Hellwig E, Schmidale S, Sculean A, Arweiler NB (2005) Efficacy, side-effects and patients' acceptance of different bleaching techniques (OTC, in-office, at-home). Oper Dent 30:156–163

Baba N, Taira Y, Matsumura H, Atsuta M (2002) Surface treatment of dentin with GLUMA and iron compounds for bonding indirect restorations. J Oral Rehabil 29:1052–1058

Balladares L, Alegría-Acevedo LF, Montenegro-Arana A, Arana-Gordillo LA, Pulido C, Salazar-Gracez MT, Reis A, Loguercio AD (2019) Effects of pH and application technique of in-office bleaching gels on hydrogen peroxide penetration into the pulp chamber. Oper Dent 44:659–667

Basting RT, Amaral FL, Franca FM, Florio FM (2012) Clinical comparative study of the effectiveness of and tooth sensitivity to 10% and 20% carbamide peroxide home-use and 35% and 38% hydrogen peroxide in-office bleaching materials containing desensitizing agents. Oper Dent 37:464–473

Bedran-Russo AK, Pauli GF, Chen SN, McAlpine J, Castellan CS, Phansalkar RS, Aguiar TR, Vidal CM, Napotilano JG, Nam JW, Leme AA (2014) Dentin biomodification: strategies, renewable resources and clinical applications. Dent Mater 30:62–76

Bernardon JK, Sartori N, Ballarin A, Perdigao J, Lopes GC, Baratieri LN (2010) Clinical performance of vital bleaching techniques. Oper Dent 35:3–10

Bonafe E, Bacovis CL, Iensen S, Loguercio AD, Reis A, Kossatz S (2013) Tooth sensitivity and efficacy of in-office bleaching in restored teeth. J Dent 41:363–369

Bortolatto JF, Pretel H, Floros MC, Luizzi AC, Dantas AA, Fernandez E, Moncada G, de Oliveira OB Jr (2014) Low concentration H(2)O(2)/TiO_N in office bleaching: a randomized clinical trial. J Dent Res 93:66S–71S

Bowles WH, Ugwuneri Z (1987) Pulp chamber penetration by hydrogen peroxide following vital bleaching procedures. J Endod 13:375–377

Buchalla W, Attin T (2007) External bleaching therapy with activation by heat, light or laser--a systematic review. Dent Mater 23:586–596

Burki Z, Watkins S, Wilson R, Fenlon M (2013) A randomised controlled trial to investigate the effects of dehydration on tooth colour. J Dent 41:250–257

Cadenaro M, Breschi L, Nucci C, Antoniolli F, Visintini E, Prati C, Matis BA, Di Lenarda R (2008) Effect of two in-office whitening agents on the enamel surface in vivo: a morphological and non-contact profilometric study. Oper Dent 33:127–134

Cadenaro M, Navarra CO, Mazzoni A, Nucci C, Matis BA, Di Lenarda R, Breschi L (2010) An in vivo study of the effect of a 38 percent hydrogen peroxide in-office whitening agent on enamel. J Am Dent Assoc 141:449–454

Cardenas AFM, Maran BM, Araújo LCR, de Siqueira FSF, Wambier LM, Gonzaga CC, Loguercio AD, Reis A (2019) Are combined bleaching techniques better than their sole application? A systematic review and meta-analysis. Clin Oral Investig 23:3673–3689

Carregosa Santana ML, Leal PC, Reis A, Faria-E-Silva AL (2019) Effect of anti-inflammatory and analgesic drugs for the prevention of bleaching-induced tooth sensitivity: a systematic review and meta-analysis. J Am Dent Assoc 150:818–829

Charakorn P, Cabanilla LL, Wagner WC, Foong WC, Shaheen J, Pregitzer R, Schneider D (2009) The effect of preoperative ibuprofen on tooth sensitivity caused by in-office bleaching. Oper Dent 34:131–135

Chen JH, Xu JW, Shing CX (1993) Decomposition rate of hydrogen peroxide bleaching agents under various chemical and physical conditions. J Prosthet Dent 69:46–48

Cook SP, McCleskey EW (2002) Cell damage excites nociceptors through release of cytosolic ATP. Pain 95:41–47

Cooper JS, Bokmeyer TJ, Bowles WH (1992) Penetration of the pulp chamber by carbamide peroxide bleaching agents. J Endod 18:315–317

Coppla FM, Rezende M, de Paula E, Farago PV, Loguercio AD, Kossatz S, Reis A (2018) Combination of acetaminophen/codeine analgesics does not avoid bleaching-induced tooth sensitivity: a randomized, triple-blind two-center clinical trial. Oper Dent 43:E53–E63

Costa CA, Riehl H, Kina JF, Sacono NT, Hebling J (2010) Human pulp responses to in-office tooth bleaching. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 109:e59–e64

Costa R, Moraes S, Lemos C, Souto Maior JR, Vasconcelos BDE, Pellizzer EP (2020) Effect of analgesic drugs on tooth sensitivity induced by in-office dental bleaching: a systematic review and meta-analysis. Oper Dent 45:E66–E76

da Costa JB, McPharlin R, Paravina RD, Ferracane JL (2010) Comparison of at-home and in-office tooth whitening using a novel shade guide. Oper Dent 35:381–388

Dahl JE, Pallesen U (2003) Tooth bleaching--a critical review of the biological aspects. Crit Rev Oral Biol Med 14:292–304

de Geus JL, de Lara MB, Hanzen TA, Fernandez E, Loguercio AD, Kossatz S, Reis A (2015) One-year follow-up of at-home bleaching in smokers before and after dental prophylaxis. J Dent 43:1346–1351

de Mendonça RP, Baliza JR, Burey A, Cavalcante LM, Loguercio AD, Calazans FS, Barceleiro MO (2021) In vitro analysis of the pH stability of dental bleaching gels during in-office procedures. J Clin Exp Dent 13:e22–e29

de Paula EA, Loguercio AD, Fernandes D, Kossatz S, Reis A (2013) Perioperative use of an anti-inflammatory drug on tooth sensitivity caused by in-office bleaching: a randomized, triple-blind clinical trial. Clin Oral Investig 17:2091–2097

de Paula EA, Kossatz S, Fernandes D, Loguercio AD, Reis A (2014) Administration of ascorbic acid to prevent bleaching-induced tooth sensitivity: a randomized triple-blind clinical trial. Oper Dent 39:128–135

de Paula EA, Nava JA, Rosso C, Benazzi CM, Fernandes KT, Kossatz S, Loguercio AD, Reis A (2015) In-office bleaching with a two- and seven-day intervals between clinical sessions: a randomized clinical trial on tooth sensitivity. J Dent 43:424–429

de Silva GM, Brackett MG, Haywood VB (2006) Number of in-office light-activated bleaching treatments needed to achieve patient satisfaction. Quintessence Int 37:115–120

Deliperi S, Bardwell DN, Papathanasiou A (2004) Clinical evaluation of a combined in-office and take-home bleaching system. J Am Dent Assoc 135:628–634

Dietschi D, Rossier S, Krejci I (2006) In vitro colorimetric evaluation of the efficacy of various bleaching methods and products. Quintessence Int 37:515–526

Diniz A, Lima S, Tavarez R, Borges AH, Pinto S, Tonetto MR, Loguercio AD, Bandéca MC (2018) Preventive use of a resin-based desensitizer containing glutaraldehyde on tooth sensitivity caused by in-office bleaching: a randomized, single-blind clinical trial. Oper Dent 43:472–481

Eimar H, Marelli B, Nazhat SN, Abi Nader S, Amin WM, Torres J, de Albuquerque RF Jr, Tamimi F (2011) The role of enamel crystallography on tooth shade. J Dent 39(Suppl 3): e3–e10

Eimar H, Ghadimi E, Marelli B, Vali H, Nazhat SN, Amin WM, Torres J, Ciobanu O, Albuquerque Junior RF, Tamimi F (2012a) Regulation of enamel hardness by its crystallographic dimensions. Acta Biomater 8:3400–3410

Eimar H, Siciliano R, Abdallah MN, Nader SA, Amin WM, Martinez PP, Celemin A, Cerruti M, Tamimi F (2012b) Hydrogen peroxide whitens teeth by oxidizing the organic structure. J Dent 40(Suppl 2):e25–e33

Fattibene P, Carosi A, De Coste V, Sacchetti A, Nucara A, Postorino P, Dore P (2005) A comparative EPR, infrared and Raman study of natural and deproteinated tooth enamel and dentin. Phys Med Biol 50:1095–1108

Favoreto MW, Carneiro TS, Andrade HF, Burey A, Dreweck FDS, Loguercio AD, Reis A (2023) Use of calcium-containing bioactive desensitizers in dental bleaching: a systematic review and meta-analyses. J Am Dent Assoc 154:245–259.

Fondriest J (2003) Shade matching in restorative dentistry: the science and strategies. Int J Periodontics Restorative Dent 23:467–479

Freire A, Archegas LR, de Souza EM, Vieira S (2009) Effect of storage temperature on pH of in-office and at-home dental bleaching agents. Acta Odontol Latinoam 22:27–31

Frysh H, Bowles WH, Baker F, Rivera-Hidalgo F, Guillen G (1995) Effect of pH on hydrogen peroxide bleaching agents. J Esthet Dent 7:130–133

Fuss Z, Szajkis S, Tagger M (1989) Tubular permeability to calcium hydroxide and to bleaching agents. J Endod 15:362–364

Giachetti L, Bertini F, Bambi C, Nieri M, Scaminaci Russo D (2010) A randomized clinical trial comparing at-home and in-office tooth whitening techniques: a nine-month follow-up. J Am Dent Assoc 141:1357–1364

Gokay O, Yilmaz F, Akin S, Tuncbilek M, Ertan R (2000) Penetration of the pulp chamber by bleaching agents in teeth restored with various restorative materials. J Endod 26:92–94

Haywood VB (2005) Treating sensitivity during tooth whitening. Compend Contin Educ Dent 26:11–20

He LB, Shao MY, Tan K, Xu X, Li JY (2012) The effects of light on bleaching and tooth sensitivity during in-office vital bleaching: a systematic review and meta-analysis. J Dent 40:644–653

Huynh MP, Yagiela JA (2003) Current concepts in acute pain management. J Calif Dent Assoc 31:419–427

Joiner A (2006) The bleaching of teeth: a review of the literature. J Dent 34:412–419

Kawamoto K, Tsujimoto Y (2004) Effects of the hydroxyl radical and hydrogen peroxide on tooth bleaching. J Endod 30:45–50

Kielbassa AM, Maier M, Gieren AK, Eliav E (2015) Tooth sensitivity during and after vital tooth bleaching: a systematic review on an unsolved problem. Quintessence Int 46:881–897

Kishi A, Otsuki M, Sadr A, Ikeda M, Tagami J (2011) Effect of light units on tooth bleaching with visible-light activating titanium dioxide photocatalyst. Dent Mater J 30:723–729

Kiyuna RC, Martins LM, Hanzen TA, Reis A, Loguercio AD, Silva LM (2021) Comparison of the effect of agitation on whitening and tooth sensitivity of in-office bleaching: a randomized clinical trial. Oper Dent 46:143–150

Klaric E, Par M, Profeta I, Kopjar N, Rozgaj R, Kasuba V, Zeljezic D, Tarle Z (2013) Genotoxic effect of two bleaching agents on oral mucosa. Cancer Genomics Proteomics 10:209–215

Kose C, Calixto AL, Bauer J, Reis A, Loguercio AD (2016) Comparison of the efffects of in-office bleaching times on whitening and tooth sensitivity: a single blind, randomized clinical trial. Oper Dent 41:138–145

Kossatz S, Dalanhol AP, Cunha T, Loguercio A, Reis A (2011) Effect of light activation on tooth sensitivity after in-office bleaching. Oper Dent 36:251–257

Kossatz S, Martins G, Loguercio AD, Reis A (2012) Tooth sensitivity and bleaching effectiveness associated with use of a calcium-containing in-office bleaching gel. J Am Dent Assoc 143:e81–e87

Kugel G, Perry RD, Hoang E, Scherer W (1997) Effective tooth bleaching in 5 days: using a combined in-office and at-home bleaching system. Compend Contin Educ Dent 18(378):380–373

Kugel G, Ferreira S, Sharma S, Barker ML, Gerlach RW (2009) Clinical trial assessing light enhancement of in-office tooth whitening. J Esthet Restor Dent 21:336–347

Loguercio AD, Tay LY, Herrera DR, Bauer J, Reis A (2015) Effectiveness of nano-calcium phosphate paste on sensitivity during and after bleaching: a randomized clinical trial. Braz Oral Res 29:1–7

Loguercio AD, Servat F, Stanislawczuk R, Mena-Serrano A, Rezende M, Prieto MV, Cereño V, Rojas MF, Ortega K, Fernandez E, Reis A (2017) Effect of acidity of in-office bleaching gels on tooth sensitivity and whitening: a two-center double-blind randomized clinical trial. Clin Oral Investig 21:2811–2818

Luque-Martinez I, Reis A, Schroeder M, Muñoz MA, Loguercio AD, Masterson D, Maia LC (2016) Comparison of efficacy of tray-delivered carbamide and hydrogen peroxide for at-home bleaching: a systematic review and meta-analysis. Clin Oral Investig 20:1419–1433

Majeed A, Grobler SR, Moola MH (2011) The pH of various tooth-whitening products on the south African market. SADJ 66:278–281

Maran BM, Burey A, de Paris MT, Loguercio AD, Reis A (2018) In-office dental bleaching with light vs. without light: a systematic review and meta-analysis. J Dent 70:1–13

Maran BM, Ziegelmann PK, Burey A, de Paris MT, Loguercio AD, Reis A (2019) Different light-activation systems associated with dental bleaching: a systematic review and a network meta-analysis. Clin Oral Investig 23:1499–1512

Maran BM, Matos TP, de Castro ADS, Vochikovski L, Amadori AL, Loguercio AD, Reis A, Berger SB (2020a) In-office bleaching with low/medium vs. high concentrate hydrogen peroxide: a systematic review and meta-analysis. J Dent 103:103499

Maran BM, Vochikovski L, Hortkoff DRA, Stanislawczuk R, Loguercio AD, Reis A (2020b) Bleaching sensitivity with a desensitizing in-office bleaching gel: a randomized double-blind clinical trial. Quintessence Int 51:788–797

Markowitz K (2010) Pretty painful: why does tooth bleaching hurt? Med Hypotheses 74:835–840

Marson FC, Sensi LG, Reis R (2008a) Novo conceito na clareação dentária pela técnica no consultório. Rev Dental Press Estet 5:55–66

Marson FC, Sensi LG, Vieira LC, Araujo E (2008b) Clinical evaluation of in-office dental bleaching treatments with and without the use of light-activation sources. Oper Dent 33:15–22

Martin J, Vildosola P, Bersezio C, Herrera A, Bortolatto J, Saad JR, Oliveira OB Jr, Fernandez E (2015) Effectiveness of 6% hydrogen peroxide concentration for tooth bleaching-A double-blind, randomized clinical trial. J Dent 43:965–972

Martini EC, Favoreto MW, Rezende M, de Geus JL, Loguercio AD, Reis A (2021) Topical application of a desensitizing agent containing potassium nitrate before dental bleaching: a systematic review and meta-analysis. Clin Oral Investig 25:4311–4327

Martins I, Onofre S, Franco N, Martins LM, Montenegro A, Arana-Gordillo LA, Reis A, Loguercio AD, da Silva LM (2018) Effectiveness of in-office hydrogen peroxide with two different protocols: a two-center randomized clinical trial. Oper Dent 43:353–361

Matis BA, Cochran MA, Franco M, Al-Ammar W, Eckert GJ, Stropes M (2007) Eight in-office tooth whitening systems evaluated in vivo: a pilot study. Oper Dent 32:322–327

Matis BA, Cochran MA, Wang G, Eckert GJ (2009) A clinical evaluation of two in-office bleaching regimens with and without tray bleaching. Oper Dent 34:142–149

McCaslin AJ, Haywood VB, Potter BJ, Dickinson GL, Russell CM (1999) Assessing dentin color changes from nightguard vital bleaching. J Am Dent Assoc 130:1485–1490

Mehta D, Venkata S, Naganath M, LingaReddy U, Ishihata H, Finger WJ (2013) Clinical trial of tooth desensitization prior to in-office bleaching. Eur J Oral Sci 121:477–481

Meireles SS, Santos IS, Bona AD, Demarco FF (2010) A double-blind randomized clinical trial of two carbamide peroxide tooth bleaching agents: 2-year follow-up. J Dent 38:956–963

Meireles SS, Santos ME, Lustosa ÍMC, Leite ELL (2021) Effects of a reduced in-office bleaching protocol with 37.5% hydrogen peroxide on effectiveness and tooth sensitivity: a double-blind randomized clinical trial. J Esthet Restor Dent 33:824–831

Moghadam FV, Majidinia S, Chasteen J, Ghavamnasiri M (2013) The degree of color change, rebound effect and sensitivity of bleached teeth associated with at-home and power bleaching techniques: a randomized clinical trial. Eur J Dent 7:405–411

Mondelli RF, Azevedo JF, Francisconi AC, Almeida CM, Ishikiriama SK (2012) Comparative clinical study of the effectiveness of different dental bleaching methods - two year follow-up. J Appl Oral Sci 20:435–443

Ontiveros JC (2011) In-office vital bleaching with adjunct light. Dent Clin North Am 55:241–253.
Ontiveros JC, Paravina RD (2009) Color change of vital teeth exposed to bleaching performed with and without supplementary light. J Dent 37:840–847
Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, Sakai M, Takahashi H, Tashkandi E, Perez Mdel M (2015) Color difference thresholds in dentistry. J Esthet Restor Dent 27(Suppl 1):S1–S9
Parreiras S, Mena-Serrano A, Moreira CG, Otuki M, Loguercio D, Reis A (2014) Penetration and cytotoxicity of a bleaching gel activated by LED/laser in restored teeth. Am J Dent 27:301–306
Patri G, Agnihotri Y, Rao SR, Lakshmi N, Das S (2013) An in vitro spectrophotometric analysis of the penetration of bleaching agent into the pulp chamber of intact and restored teeth. J Clin Diagn Res 7:3057–3059
Paula E, Kossatz S, Fernandes D, Loguercio A, Reis A (2013) The effect of perioperative ibuprofen use on tooth sensitivity caused by in-office bleaching. Oper Dent 38:601–608
Pintado-Palomino K, Peitl Filho O, Zanotto ED, Tirapelli C (2015) A clinical, randomized, controlled study on the use of desensitizing agents during tooth bleaching. J Dent 43:1099–1105
Pontes M, Gomes J, Lemos C, Leão RS, Moraes S, Vasconcelos B, Pellizzer EP (2020) Effect of bleaching gel concentration on tooth color and sensitivity: a systematic review and meta-analysis. Oper Dent 45:265–275
Price RB, Sedarous M, Hiltz GS (2000) The pH of tooth-whitening products. J Can Dent Assoc 66:421–426
Qin C, Xu J, Zhang Y (2006) Spectroscopic investigation of the function of aqueous 2-hydroxyethylmethacrylate/glutaraldehyde solution as a dentin desensitizer. Eur J Oral Sci 114:354–359
Reis A, Dalanhol AP, Cunha TS, Kossatz S, Loguercio AD (2011a) Assessment of tooth sensitivity using a desensitizer before light-activated bleaching. Oper Dent 36:12–17
Reis A, Tay LY, Herrera DR, Kossatz S, Loguercio AD (2011b) Clinical effects of prolonged application time of an in-office bleaching gel. Oper Dent 36:590–596
Reis A, Kossatz S, Martins GC, Loguercio AD (2013) Efficacy of and effect on tooth sensitivity of in-office bleaching gel concentrations: a randomized clinical trial. Oper Dent 38:386–393
Rezende M, Loguercio AD, Reis A, Kossatz S (2013) Clinical effects of exposure to coffee during at-home vital bleaching. Oper Dent 38:E229–E236
Rezende M, Bonafe E, Vochikovski L, Farago PV, Loguercio AD, Reis A, Kossatz S (2016a) Pre- and postoperative dexamethasone does not reduce bleaching-induced tooth sensitivity: a randomized, triple-masked clinical trial. J Am Dent Assoc 147:41–49
Rezende M, Ferri L, Kossatz S, Reis A, Loguercio A (2016b) Combined bleaching technique using low and high hydrogen peroxide in-office bleaching gel. Oper Dent 41:388–396
Rezende M, Loguercio AD, Kossatz S, Reis A (2016c) Predictive factors on the efficacy and risk/intensity of tooth sensitivity of dental bleaching: a multi regression and logistic analysis. J Dent 45:1–6
Roderjan DA, Stanislawczuk R, Hebling J, Costa CA, Reis A, Loguercio AD (2015) Response of human pulps to different in-office bleaching techniques: preliminary findings. Braz Dent J 26:242–248
Sakai K, Kato J, Kurata H, Nakazawa T, Akashi G, Kameyama A, Hirai Y (2007) The amounts of hydroxyl radicals generated by titanium dioxide and 3.5% hydrogen peroxide under 405-nm diode laser irradiation. Laser Phys 17:1062–1066
Salem YM, Osman YI (2011) The effect of in-office vital bleaching and patient perception of the shade change. SADJ 66(70):72–76
SoutoMaior JR, de Moraes S, Lemos C, Vasconcelos BDE, Montes M, Pellizzer EP (2019) Effectiveness of light sources on in-office dental bleaching: a systematic review and meta-analyses. Oper Dent 44:E105–E117
Spalding M, Taveira LA, de Assis GF (2003) Scanning electron microscopy study of dental enamel surface exposed to 35% hydrogen peroxide: alone, with saliva, and with 10% carbamide peroxide. J Esthet Restor Dent 15:154–164; discussion 165

Strobl A, Gutknecht N, Franzen R, Hilgers RD, Lampert F, Meister J (2010) Laser-assisted in-office bleaching using a neodymium:yttrium-aluminum-garnet laser: an in vivo study. Lasers Med Sci 25:503–509

Sulieman M, Addy M, Rees JS (2003) Development and evaluation of a method in vitro to study the effectiveness of tooth bleaching. J Dent 31:415–422

Swift EJ Jr (2005) Tooth sensitivity and whitening. Compend Contin Educ Dent 26:4–10. quiz 23

Tavares M, Stultz J, Newman M, Smith V, Kent R, Carpino E, Goodson JM (2003) Light augments tooth whitening with peroxide. J Am Dent Assoc 134:167–175

Tay LY, Kose C, Loguercio AD, Reis A (2009) Assessing the effect of a desensitizing agent used before in-office tooth bleaching. J Am Dent Assoc 140:1245–1251

Tay LY, Kose C, Herrera DR, Reis A, Loguercio AD (2012) Long-term efficacy of in-office and at-home bleaching: a 2-year double-blind randomized clinical trial. Am J Dent 25:199–204

Torres CR, Crastechini E, Feitosa FA, Pucci CR, Borges AB (2014) Influence of pH on the effectiveness of hydrogen peroxide whitening. Oper Dent 39:E261–E268

Vochikovski L, Rezende M, Maran BM, de Paula J, Machado LB, Kossatz S, Loguercio AD, Reis A (2022) Combined bleaching technique versus at-home bleaching-a single-blind randomized controlled trial. Oper Dent 47:247–257

Wang Y, Gao J, Jiang T, Liang S, Zhou Y, Matis BA (2015) Evaluation of the efficacy of potassium nitrate and sodium fluoride as desensitizing agents during tooth bleaching treatment - a systematic review and meta-analysis. J Dent 43:913–923

Watts A, Addy M (2001) Tooth discolouration and staining: a review of the literature. Br Dent J 190:309–316

Zekonis R, Matis BA, Cochran MA, Al Shetri SE, Eckert GJ, Carlson TJ (2003) Clinical evaluation of in-office and at-home bleaching treatments. Oper Dent 28:114–121

Ziemba SL, Felix H, MacDonald J, Ward M (2005) Clinical evaluation of a novel dental whitening lamp and light-catalyzed peroxide gel. J Clin Dent 16:123–127

Intracoronal Whitening of Root-Filled Teeth

8

Dina Mansour, Ronald Ordinola Zapata, and Jorge Perdigão

Abstract

Several techniques have been used within the last decades to lighten discolored root-filled teeth. Internal bleaching or intracoronal whitening offers some advantages over more invasive treatments: (1) it is relatively easy to carry out; (2) it involves the removal of minimal tooth structure; and (3) the cost of treatment is low compared to that of other restorative options including full- and partial-coverage restorations.

8.1 Introduction

Esthetic dentistry has been a popular topic since the late 1800s (Harlan 1884). Tooth discoloration in the maxillary anterior teeth is considered an undesirable consequence following root canal treatment as it creates a range of esthetic problems (Kingsbury 1861; Miller 1903; Ahmed and Abbott 2012). The most common causes of discoloration of root-filled teeth are pulpal injuries from dental trauma, pulp canal obliteration, contamination of the pulp chamber with pulp tissue remnants, amalgam restorations, microleakage around old resin composite restorations, sequelae from regenerative

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endodontic procedures, and root-filling materials including sealers and MTA (mineral trioxide aggregate) (Plotino et al. 2008; Jang et al. 2013; Frank et al. 2022).

Hemorrhage of the dental pulp during pulp extirpation or trauma can diffuse through dentinal tubules. The hemolysis of red blood cells releases iron which combined with hydrogen sulfate produces ferric sulfide, a dark substance that stains dentin (Arens 1989; Rotstein 1993; Coelho et al. 2020; Frank et al. 2022). The blood decomposition leads to the deposition of chromogenic blood degradation products such as hemosiderin, hemin, hematin, and hematoidin (Greenwall-Cohen et al. 2018; Irusa et al. 2022).

The goal of dental bleaching is to restore the tooth normal color by decolorizing an intrinsic stain through the process of oxidation or to enhance the natural shade of the dentition by bleaching all the teeth (Rotstein et al. 2008). It has been described that bleaching techniques are more predictable when the etiology of discoloration is due to pulp decomposition of organic products or chromogenic bacteria within the dentinal tubules (Plotino et al. 2008). Bleaching has a questionable prognosis when discoloration is due to metallic salts or mineralized entities (Plotino et al. 2008).

The internal bleaching procedure is a less invasive treatment and has a relatively low cost compared to full-coverage restorations or veneers. A few bleaching agents have been used. Hydrogen peroxide, carbamide peroxide, and sodium perborate have been recommended by several authors (Prinz 1924; Brown 1965; Boksman et al. 1983; Carrillo et al. 1988; Vachon et al. 1998). Two substances – hydrogen peroxide and sodium perborate powder – have been utilized both separately and in combination (Weisman 1963; Nutting and Poe 1967; Freccia et al. 1982). The bleaching effect has been attributed to the active oxygen and free radicals produced by hydrogen peroxide (Kashima-Tanaka et al. 2003).

8.2 Etiology of Discoloration in Root-Filled Teeth

Discoloration in root-filled teeth can be of intrinsic or extrinsic etiology (Hattab et al. 1999; Plotino et al. 2008). A successful outcome of the nonvital bleaching technique relies on the etiology of the discoloration. Thus, an accurate identification of the predisposing factors and the selection of the bleaching agent recommended for the specific case are essential. Extrinsic stains occur when external chromogens settle on the tooth surface, being the most common dietary, tobacco, and chromogenic bacteria (Plotino et al. 2008). Intrinsic stains (Fig. 8.1) occur either locally due to the chromogens located inside the dentin or systemically (Şişmanoğlu 2020). The permanent dentition can be impacted by metabolic and genetic diseases including porphyria, jaundice, or erythroblastosis fetalis (Plotino et al. 2008). Discolorations linked to systemic drug intake include antibiotics and excess fluoride, which can be iatrogenic or from drinking water (Sherwood 2010). It is important to notice that intrinsic stains in root-filled teeth affect dentin but not enamel (van der Burgt et al. 1986).

A limitation of many sealers and endodontic dressings is their potential for staining. These materials include AH26 (Dentsply Sirona, Charlotte, NC, USA),

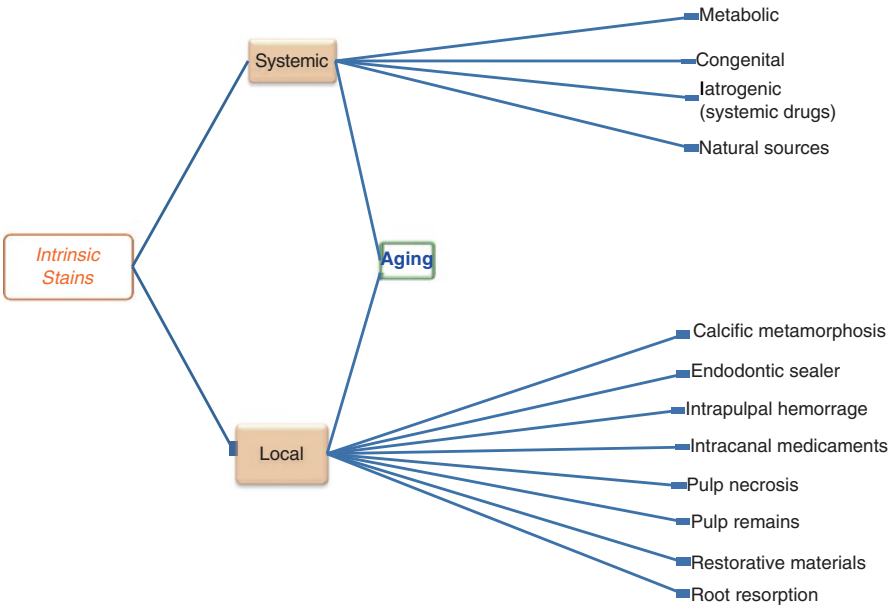


Fig. 8.1 Causes of intrinsic stains

Grossman sealer, MTA, calcium hydroxide dressings that include tetracycline or iodine in their composition, and the triple antibiotic paste used in regenerative endodontic procedures (Dabbagh et al. 2002). MTA is a common endodontic cement that contains bismuth oxide as a radiopacifier. Tetracycline and heavy metals such as bismuth can produce tooth discoloration. In vitro research models have demonstrated that gray and white MTA Angelus (Angelus Indústria de Produtos Odontológicos S/A, Londrina, PR, Brazil), ProRoot MTA (Dentsply Sirona), and OrthoMTA (BioMTA, Seoul, Korea) are likely to stain the tooth structure (Możyńska et al. 2017). Marciano et al. (2015) showed that MTA Angelus in contact with dentin previously treated with sodium hypochlorite resulted in color changes from light yellow to dark brown at the cement-dentin interface.

Newer materials have been developed to reduce the staining potential by decreasing the heavy metal content, such as iron or bismuth, in the composition of sealers and cements (Keskin et al. 2015). For example, zirconium oxide and calcium tungstate have been used to replace bismuth oxide as a radiopacifier in endodontic sealers. In a laboratory study, Kang et al. (2015) found that discs of MTA-based materials containing a zirconium oxide radiopacifier instead of bismuth oxide exhibited color stability, while those with bismuth oxide demonstrated significant dark staining. Thus, tooth staining is significantly reduced using dental products that lack bismuth oxide (Kang et al. 2015). In the esthetic zone, such as the maxillary and mandibular anterior area, compounds free of bismuth oxide, such as Biodentine (Septodont, Lancaster, PA, USA) and BioAggregate (Innovative Bioceramix, Vancouver, BC, Canada), are viable alternatives to MTA (Keskin et al. 2015). In addition, tooth

discoloration can be minimized by searing off the obturation material below the cemento-enamel junction (CEJ) level.

Tooth discoloration can also be caused by triple antibiotic paste, an intracanal dressing used during regenerative endodontic procedures (Kim et al. 2010). Kohli et al. (2015) found that triple antibiotic paste, white MTA, and gray MTA caused a significant coronal tooth discoloration at 7 days and 6 months. EndoSequence RRM putty (Brasseler USA Dental, Savannah, GA, USA) and Biodentine (Septodont), materials that lack bismuth oxide, did not cause discoloration (Kohli et al. 2015). A case series study by Petrino et al. (2010) found that there is a potential for staining in the anterior teeth when antibiotic intracanal dressings containing minocycline are used in immature teeth. The triple antibiotic paste used in regenerative endodontic procedures is composed of minocycline, metronidazole, and ciprofloxacin. These substances, especially tetracycline, can produce strong coronal discoloration (Abou-Rass 1988; Venkataraman et al. 2019). Jimenez-Padilla et al. (2022) reported that two sessions of internal bleaching with hydrogen peroxide and sodium perborate can recover color changes induced by regenerative endodontic procedures. This chapter will focus on stains of *intrinsic* origin. Local causes of posteruptive intrinsic stains can be found in previous chapters.

8.3 Treatment Plan Considerations

When addressing bleaching of root-filled teeth, Salvas (1938) wrote, "bleaching teeth is, at best, more or less of an unsatisfactory operation." The unpredictability of intracoronal whitening has not changed considerably since the author made this statement in 1938. Overall, long-term studies are scarce (Frank et al. 2022). The etiology of the discoloration must be identified as part of the consultation visit. The treatment prognosis, including the limitations of intracoronal whitening, needs to be shared with the patient. The patient must also be informed that radicular dentin does not respond satisfactorily to external or internal bleaching procedures (Kwon 2011). This is important in cases where there is a gingival recession that results in a visible exposure of the root surface.

Kahler (2022a, b) has summarized different treatment options for discolored teeth including external bleaching, internal bleaching, and prosthodontic options – resin composite, ceramic veneers, and crowns. Also periodontal considerations such as root color and tooth shape and form should be considered in the treatment planning.

The indications and contraindications for intracoronal whitening are displayed in Table 8.1. It is also important to share with the patient all the treatment options to improve the esthetics of a root-filled tooth. Discolored teeth with a history of dental trauma must undergo vitality testing (Greenwall-Cohen et al. 2018). A detailed clinical exam must document the presence of craze lines on the enamel, ideally under magnification. Defective restorations and other marginal microgaps that may result in leakage of the intracoronal bleaching agents to the surrounding tissues need to be recorded, as seen in Chap. 4. The use of transillumination to diagnose

Table 8.1 Indications and contraindications for internal whitening of endodontically treated teeth

Indications	Contraindications
Discolorations from pulpal trauma or pulp remains	Discolorations restricted to enamel
Discolorations that do not respond to external bleaching techniques	Untreated caries lesions
Dentin discolorations of various origins	Loss of coronal tooth structure that prevents sealing of the bleaching material inside the pulp chamber
	Defective restorations or defective enamel that may result in seepage of the bleaching material to the periodontal tissues
	Patient's high expectations
	Pregnancy

microgaps and craze lines is advised. Additionally, a history of dental trauma, a common cause of tooth discoloration, is associated with damage to the precementum layer which can predispose the tooth to external invasive cervical resorption (EICR) and ultimately to replacement.

The treatment plan must be based on existing evidence to improve the chance of clinical success. Intraoral photographs are essential to document the baseline color. Although the color of stained root-filled teeth is not usually within the range of universal shade guides, the clinician may still take a photograph with a tab from the Vita Classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) adjacent to the tooth to be treated. This will provide a comparative reference (baseline) between the postoperative and preoperative condition. The prognosis of internal whitening finally will depend on several factors, including the etiology and the duration of the discoloration.

8.4 Whitening Techniques for Root-Filled Teeth

8.4.1 Thermocatalytic Technique

Fischer (1911) reported heating hydrogen peroxide with a special mercury arc light with a quartz lens, or Kromayer lamp, to irradiate the teeth with ultraviolet (UV) rays to mimic the sunlight. Prinz (1924) recommended using heated solutions consisting of sodium perborate and Superoxol for cleaning the pulp cavity. Dietz (1957) recommended a 20-in infrared light for the thermocatalytic technique. In 1963, the use of 30% hydrogen peroxide with a source of light and heat from a distance of 5 cm was reported (Weisman 1963).

The thermocatalytic technique is comparable to the conventional technique where a variety of heat sources are used to release reactive oxygen quickly. This method has been abandoned because uncontrolled heat can produce damage to the periodontal ligament and predispose the tooth to EICR (Coelho et al. 2020). Several heat sources have been utilized as activation methods, including ultraviolet (UV) lights, infrared lights, flamed instruments, and electrical sources of light and heat.

8.4.2 Walking-Bleach Technique

In a congress report by Marsh and published by Salvas (1938), the walking-bleach technique using sodium perborate and distilled water was described (Plotino et al., 2008). The walking-bleach technique consists of delivering the bleaching agent into the access cavity. The pulp chamber is then closed with a temporary material leaving the bleaching agent for a few days. The bleaching agent will be changed on a weekly basis until an acceptable color is attained (Coelho et al. 2020). Spasser (1961) revised the sodium perborate and water mixture and recommended 30% hydrogen peroxide to increase the mixture's bleaching efficacy (Plotino et al. 2008). Nutting and Poe (1967) modified the original technique by substituting water with 30% hydrogen peroxide. Numerous authors have observed that three applications of sodium perborate mixed with water are as effective as applying sodium perborate and 30% hydrogen peroxide solution (Rotstein et al. 1991c, 1993a; Holmstrup et al. 1988). Carbamide peroxide has also been suggested alone or in combination with sodium perborate (de Souza-Zaroni et al. 2009). A recent systematic review and meta-analysis reported that carbamide peroxide, hydrogen peroxide, and the combination of sodium perborate and hydrogen peroxide resulted in a significantly bleaching effect compared to the use of sodium perborate alone (Frank et al. 2022).

The walking-bleach and the combined techniques have both proven to be effective and produced comparable esthetic effects. In 57 out of 95 teeth (60%), a good or acceptable result was obtained after one or two visits (Holmstrup et al. 1988). The remaining 38 teeth (40%) were treated over 3–9 visits. The main factor of dissatisfaction for this technique is that multiple visits may be needed to achieve the desirable outcome. Furthermore, it was confirmed that older patients or older discolorations required a longer treatment period (Coelho et al. 2020). One possible explanation could be the reduced dentin permeability of older dentin. Regarding the prognosis of this technique, clinical studies revealed that failure rates increase over time. Different failure rates after 2, 5, and 8 years have been reported. Overall, the walking-bleach technique showed failure rates between 10%, 25%, and 49%, respectively (Lise et al. 2018; Coelho et al. 2020).

8.4.3 Combined Technique

The inside-outside or combined approach was proposed by Settembrini et al. (1997). This method promotes the use of a specially fitted tray to simultaneously bleach the pulp chamber walls and external surface of the tooth. In this method, the access cavity is left open, and the patient oversees the bleaching agent replacement. The outcome therefore depends on patient compliance (Coelho et al. 2020).

The combined technique has numerous advantages over the walking-bleach method, including patient control over the bleaching intensity and fewer appointments and chair time, which translates into a shorter treatment period. This protocol reduces exposure to the bleaching agent and minimizes potential long-term side effects (Coelho et al. 2020). However, the disadvantage of the combined technique, in comparison with the walking-bleach, is that the cavity remains open, increasing the risk of tooth fracture or food impaction (Coelho et al. 2020). In addition, patient's

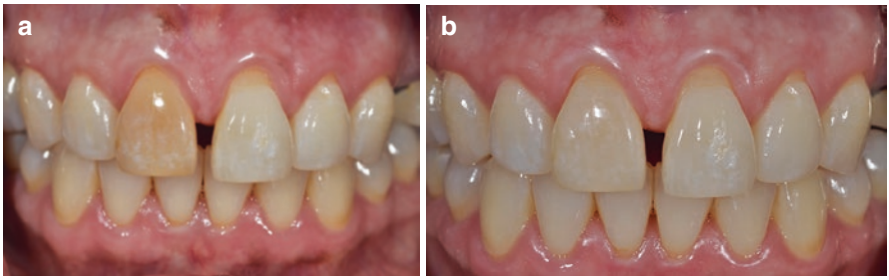


Fig. 8.2 (**a**) Tooth #8 (FDI 1.1) of this 43-year-old patient had been endodontically treated within the previous 4 years. The patient did not want to be treated with internal bleaching. After exposing a new periapical radiograph, we informed the patient that external whitening had been successful in some cases of darkened endodontically treated teeth. The patient decided to try external bleaching with a custom-fitted tray to bleach only the darker tooth with 10% carbamide peroxide gel as described in Chap. 6. (**b**) Esthetic outcome after 4 weeks

compliance and return for placing the final restoration are vital for the success of this technique. A final restoration with adhesive and composite resin should be postponed for 2 weeks since enamel and dentine are temporarily less likely to adhere to resin-based materials, including composite resin and resin-modified glass ionomers (Shinohara et al. 2005; Swift Jr 2012). This is due to the fact that it has been demonstrated that residual free oxygen and peroxide prevent polymerization of resin-based materials (Swift Jr 2012).

The immediate esthetic outcomes of the combined technique have been reported to be superior to those of the walking-bleach technique. However, the difference was not substantial at 6 months, and both techniques were equally effective (Bizhang et al. 2003).

8.4.4 External At-Home Bleaching with a Custom-Fitted Tray

As seen in Chap. 6, some discolored root-filled teeth can be successfully bleached externally using at-home bleaching in a custom-fitted tray with carbamide peroxide gel (Fig. 8.2). However, these teeth do not always respond to external tray whitening as well as vital teeth do. The prognosis of the at-home treatment of root-filled teeth with tray whitening depends on the etiology and duration of the discoloration.

8.5 Factors that Influence the Prognosis of Intracoronal Bleaching

8.5.1 Duration and Intensity of Discoloration

The success rate and prognosis of intracoronal whitening may depend on the duration of the discoloration (Brown 1965; van der Burgt and Plasschaert 1986). The success rate has been reported to be 80% and 45% after 1- and 6-years post-treatment, respectively (Irusa et al. 2022). Furthermore, Brown (1965) reported that the teeth

that had been discolored for less than 1 year had an 87.5% success rate, while for the teeth that had been discolored over 5 years, the success rate dropped to 66%. The severely discolored teeth have less chance of successful bleaching (75%) than the teeth with moderate or slight discolorations (90–100%) (Brown 1965). Gradual discolorations tend to bleach more efficiently than rapid discolorations.

8.5.2 Potential for Color Regression

Some color relapse may occur in about 50% of bleached teeth after 1 year and even more after a longer period (Brown 1965; Howell 1981). The teeth that are more difficult to bleach are more likely to relapse (Howell 1981). Specific endodontic sealers result in a higher risk of color relapse than others (van der Burgt and Plasschaert 1986). The probability of color reversal is much higher when the discoloration is due to metallic stains or silver-containing medicaments (Freccia et al. 1982). Brown (1965) performed a survey on 80 teeth that had been bleached using 30% hydrogen peroxide and compared standardized photographic records of the teeth taken before and after bleaching and at intervals of l–5 years. The author found that 20 (25%) teeth failed, of which 14 teeth failed to respond to treatment at all, while in 6 teeth the color relapsed after initially successful bleaching. Of the 60 (75%) successfully bleached teeth, 23 showed no postoperative change, but in 37 teeth there was some color regression. Stability of nonvital discolored teeth subjected to combined thermocatalytic and walking-bleach intracoronal techniques was evaluated at 16 years (1989–2005) (Amato et al. 2006). The series comprised 50 patients (age range 7–30). Thirty-five cases were evaluated after 16 years. In 22 of these cases (62.9%), the color had remained stable and was similar to that of adjacent teeth, indicating a successful outcome of the combined bleaching technique. There were 13 cases (37.1%) classified as failures because of marked color relapse. Radiographically none of the cases re-examined underwent internal or external root resorption. However, there is insufficient evidence in terms of efficacy and safety to substantiate the use of the combined technique over the walking-bleach technique.

The presence of the environmental mineral content and water are two important factors in the color regression of the bleached teeth (Li et al. 2010). The whitening effects of in vitro bleached tooth samples are not stable after 12 months. Color change of enamel, dentin, and combined enamel-dentin is mostly characterized by a decrease of lightness (Wiegand et al. 2008).

8.5.3 Patient's Age

Dentists must be cautious when whitening the teeth of children and adolescents considering that they may be more susceptible to adverse side effects (Irusa et al. 2022). It is important to note that some government regulations could restrict the use of materials containing between 0.1 and 6% hydrogen peroxide in minors (Greenwall-Cohen et al. 2018).

The success rate of the internal whitening technique is 50–90% without a direct relationship between success and patient's age (Brown 1965; Howell 1981).

However, other authors have stated that young teeth bleach faster than old teeth because of the increased dentinal permeability in younger teeth (van der Burgt and Plasschaert 1986; Feiglin 1987). Dietz (1957) reported a direct relation between the age of a tooth and its resistance to bleaching, suggesting that more permanent results were obtained with teeth of the older age groups. Camps et al. (2007) evaluated the diffusion of hydrogen peroxide through human dentin in patients under 20 years old and in patients between 40 and 60 years old. The teeth were endodontically treated, and a defect was created at the CEJ. The access cavities were filled with 20% hydrogen peroxide gel. The amount of diffusing hydrogen peroxide was assessed at 1, 24, 48, and 120 h. Diffusive flux and maximal diffusion were higher through young teeth compared to old teeth. Thus, children and adolescents may be more susceptible to adverse effects (Irusa et al. 2022). However, darker teeth in younger patients reach a higher degree of whitening (Rezende et al. 2016).

8.5.4 Type of Discoloration

The prognosis of any bleaching technique depends on the etiology of the discoloration (Freccia et al. 1982). The prognosis is favorable when the staining is caused by products of pulpal decomposition within dentinal tubules. More common discolorations caused by sealers have also a favorable prognosis (van der Burgt and Plasschaert 1985, 1986) (Fig. 8.3). In addition, discoloration induced by triple

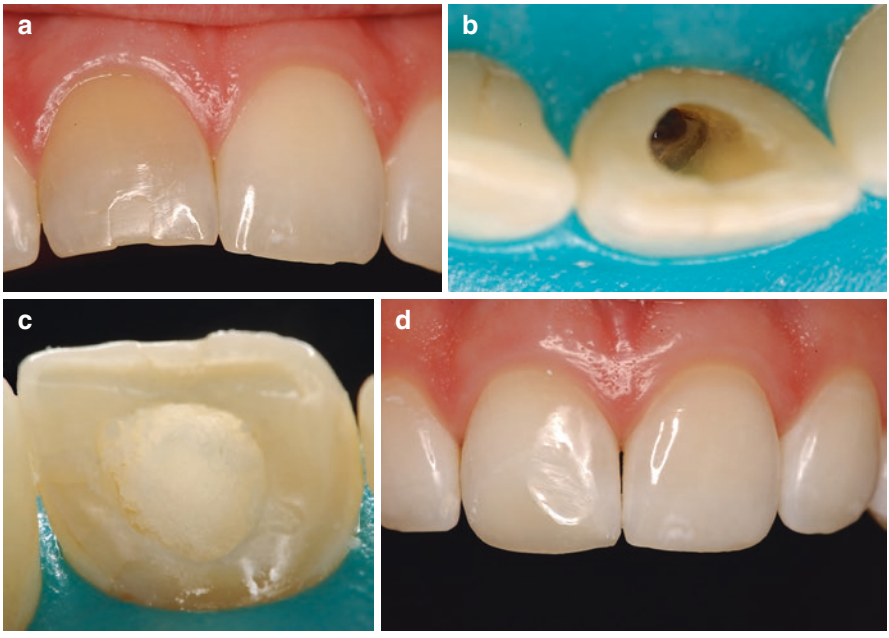


Fig. 8.3 (**a**) and (**b**) Clinical case of a recent discoloration caused by endodontic sealer in the pulp chamber. (**c**) and (**d**) This tooth was treated with the walking-bleach technique using sodium perborate mixed with distilled water after only one session

antibiotic paste can be reversed with sodium perborate paste (Kirchhoff et al. 2015). When the discoloration is due to metallic stains or silver-containing medicaments, bleaching is more difficult, and it is sometimes not possible to achieve satisfactory results. In fact, internal discoloration caused by oxidation of metals (silver, amalgam) cannot be removed with whitening treatments (Attin et al. 2003).

8.6 Adverse Effects

Hydrogen peroxide is the main toxic substance that has been used for internal bleaching (Chaps. 4 and 5). Hydrogen peroxide is a reactive oxygen species (ROS) with a low pH (Bax et al. 1992; Kashima-Tanaka et al. 2003). Free radicals and ROS exert biological actions such as inflammation, carcinogenesis, aging, and mutation (Valko et al. 2007). There is insufficient evidence in humans to support hydrogen peroxide's carcinogenicity. Hydrogen peroxide is only thought to pose a low risk of producing local carcinogenic consequences (Kahler 2022a, b). ROS also play an important role in tissue injury at the sites of inflammation in various diseases (Valko et al. 2007). Some regulatory agencies including the European Union (Chap. 6) do not allow the commercialization of products releasing values above 6% of hydrogen peroxide by dental professionals.

8.6.1 External Invasive Cervical Root Resorption

EICR is characterized by the loss of cementum, dentin, or enamel as a result of osteoclastic activity (Patel et al. 2009). Figure 8.4 shows cone-beam computed tomography images of EICR in previously treated teeth that had been unsuccessfully bleached internally prior to the restorative procedures. Table 8.2 displays a summary of the findings in clinical studies of internal whitening and the reported number of EICR cases. For many of these studies, the etiology of the tooth discoloration is not reported, aside from trauma.

It has been reported that intracoronal bleaching is a risk factor for EICR (Harrington and Natkin 1979; Lado et al. 1983; Montgomery 1984; Newton and Hayes 2020). Hydrogen peroxide can diffuse through dentinal tubules to areas depleted of radicular cementum. This produces damage to the attachment apparatus, causing inflammation, and recruitment of clastic cells. It is important to highlight that many teeth with internal bleaching indications could present a history of dental trauma. These cases are already predisposed to develop EICR. Numerous trauma scenarios including avulsion, lateral luxation, and intrusion can produce severe damage to the pulp, the precementum protective layers, and the periodontal ligament.

A study suggested that the combination of heat and hydrogen peroxide is responsible for EICR (Madison and Walton 1990). However, other clinical reports found EICR cases in which heat was not used (Goon et al. 1986; Friedman et al. 1988). Even though the walking-bleach technique with sodium perborate and hydrogen

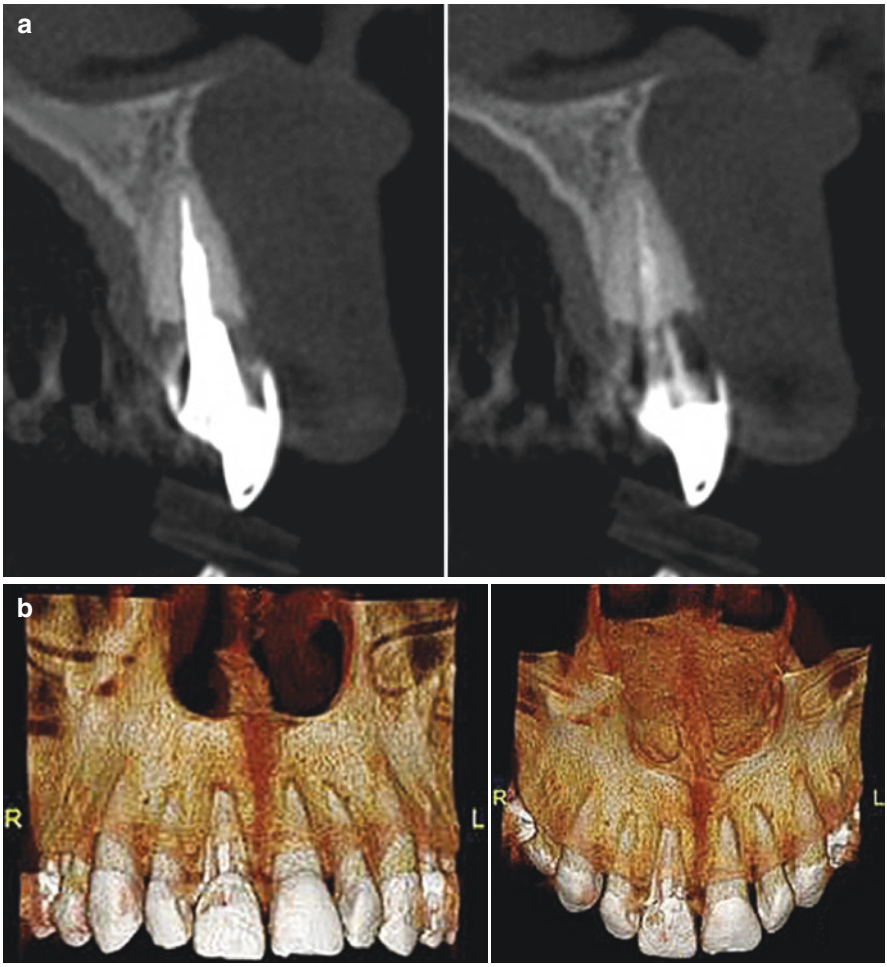


Fig. 8.4 (**a**) Cone-beam computed tomography; (**b**) reconstructed three-dimensional (3D) image showing an EICR lesion on tooth #8 (FDI 1.1). This tooth had been treated with intracoronal whitening on two different occasions but did not respond to the treatment. The EICR lesion was diagnosed after the tooth was restored with a cast core and a full-coverage restoration. *Courtesy of Dr. Eduardo Vilain de Melo, Florianópolis, Brazil*

peroxide is less harmful than the thermocatalytic technique, EICR can also occur with the walking-bleach technique (Goon et al. 1986; Latcham 1986; Friedman et al. 1988). More recently, a clinical trial found that intracoronal whitening with 35% H_2O_2 or with 37% carbamide peroxide increases the levels of cytokines associated with inflammation and bone resorption 3 months after the treatment is completed (Bersezio et al. 2020).

Several factors can contribute to the risk of EICR including anatomy of the CEJ, increase of dentinal permeability, dentinal tubule infection, and previous damage to

Table 8.2 Clinical studies of internal whitening[a]

	Number of teeth	EICR	History of trauma	Outcome
Harrington and Natkin (1979)	4 central incisors were root canal treated in 4 patients whose age ranged from 11 to 15 years of age. In 3 of the 4 cases, the thermocatalytic bleaching technique was carried out from 6 to 15 years after the trauma and completion of root canal therapy. Same authors reported 3 extra cases that developed EICR	All with EICR; all resorptive lesions occurred in the cervical third of the root	All 4 teeth	No reported outcome
Cvek and Lindvall (1985)	11 teeth with EICR after bleaching with 30% H_2O_2	2 teeth - superficial EICR that did not progress; 5 teeth - EICR followed by ankylosis; 4 teeth - EICR was progressive and associated with radiolucency in the adjacent alveolar bone	10/11, when patients were 11–16 years old	
Abou-Rass (1988)	112 severely tetracycline-stained teeth in 20 patients were root-canal treated and internally bleached with a thick paste of sodium perborate in 30% H_2O_2. The procedure was repeated after 1 week if needed	No report of EICR after 3–15 years	No history of trauma	7% failure – 8/112 teeth were noticeably dark at the cervical zone; intracoronal restorative failures were relatively high (7%); endodontic failure was only 2%, and there was no evidence of EICR

Table 8.2 (continued)

	Number of teeth	EICR	History of trauma	Outcome
Friedman et al. (1988)	58 bleached teeth were re-examined after 1–8 years	In 4/58 teeth (6.9%), the resorption started apically; 2 teeth had advanced EICR; 2 teeth had arrested EICR, one of which had been bleached with the walking-bleach technique	No trauma for the 4 teeth with EICR	43 teeth (74%) were bleached once, and 15 teeth (26%) were bleached more than once; all teeth were bleached with 30% H_2O_2; 29/58 teeth (50%) were found esthetically satisfactory; 17/58 teeth (29%) were clinically acceptable; 12/58 teeth (21%) were unacceptable, of which 4 had received full-coverage restorations
Holmstrup et al. (1988)	95 teeth, walking-bleach technique with sodium perborate moistened with water	No report of EICR at 3 years	91/95 teeth had a history of trauma	57 teeth (60%) had a good/acceptable result after 1 or 2 visits. The remaining 38 teeth were treated over 3–9 visits. Satisfactory initial result in 90% of the cases. Color relapse was observed in 20% of the teeth after 3 years
Anitua et al. (1990); Aldecoa and Mayordomo (1992)	258 intact tetracycline-stained teeth underwent elective root-canal treatment; GIC cervical barrier 1 mm below CEJ, walking-bleach technique with 30% H_2O_2 and sodium perborate; repeated 2–3 times every 4 weeks. A mix of 10% carbamide peroxide + sodium perborate was then applied for 4–6 weeks	No report of EICR at 4 and 6 years	No history of trauma	Color relapse for 6/258 teeth (2.3%) at the 4-year recall; 10% of teeth after 6 years

(continued)

Table 8.2 (continued)

	Number of teeth	EICR	History of trauma	Outcome
Heithersay et al. (1994)	204 teeth were re-examined after 1–19 years; all teeth had been treated with a combination of thermocatalytic and walking-bleach procedures using 30% H_2O_2	4 teeth (1.96%) developed invasive EICR. All of these teeth had a history of traumatic injury, and the level of gutta-percha was at the CEJ without a barrier	151/204 (77.9%) had history of traumatic injury	Not reported, as this study was based on radiographic evaluations
Glockner et al. (1999)	5-year clinical follow-up of teeth bleached with 30% H_2O_2 with sodium perborate and walking-bleach technique for 1 week; procedure repeated until satisfactory results were obtained	Not reported	Not reported	Treatment was successful in 68 patients (79%) after 5 years
Amato et al. (2006)	Thermocatalytic technique used with 35% H_2O_2 and sodium perborate heated with light source; 50 teeth were initially selected, and 35 were evaluated at 16 years	None of the 13 failures had radiographic signs of EICR. Authors stated that for the 9 teeth for which the root canal had been re-treated, 2 showed a fistula, pain, and a peri-radicular and/or latero-radicular bone lysis area that had failed to disappear or had reappeared	42 of the initial 50 teeth had a history of trauma	In 22 teeth (62.9%), the color had remained stable and was similar to that of adjacent teeth; 13 cases (37.1%) were classified as failures because of marked color relapse
Abbott and Heah (2009)	255 teeth were treated with 35% H_2O_2 and sodium perborate; some patients were followed up up to 5 years	No cases of EICR	150 of the initial 255 teeth had a history of trauma	Color improvement was rated good (87.1%) or acceptable (12.9%). The color was more stable for teeth restored with GIC/composite resin

[a]Excluding case reports of one tooth

the precementum layer, among others. The anatomy of the CEJ has called the attention of numerous researchers. The penetration of hydrogen peroxide is significantly higher in the teeth that lack the cementum protective layer at the CEJ (Rotstein et al. 1991b). To prevent the diffusion of hydrogen peroxide to the periodontal tissues,

Madison and Walton (1990) suggested that bleaching procedures should be confined to the supragingival part of the pulp chamber to prevent diffusion of bleaching agent to the periodontal tissues. Because hydrogen peroxide is the main active component in bleaching agents, a cervical seal with a resin-modified glass ionomer-based material is recommended before the intracoronal bleaching procedures. Thus, cervical barriers should be placed at the CEJ to reduce dentin permeability at this level (He and Goerig 1989; Anitua et al. 1990). Originally the location of the barrier was 1 mm apical to the CEJ (He and Goerig 1989). Other authors suggested that the barrier should be placed from the CEJ level to 2 mm below the CEJ with a minimum thickness of 1 mm (Costas and Wong 1991; Rotstein et al. 1992b). When the barrier was placed 2 mm below the CEJ, the esthetic bleaching result from a walking-bleach technique with sodium perborate and Superoxol was more acceptable than when the barrier was placed at the CEJ level (Costas and Wong 1991). A 1-mm I.R.M. (Dentsply Sirona) barrier resulted in an increased penetration of hydrogen peroxide compared to a 2-mm-thick barrier (Rotstein et al. 1992b). Internal measurements can be used to validate where the intracanal seal should be placed in relation to periodontal probing of the epithelial attachment at the mesial, distal, labial, and palatal sides of the tooth (Kahler 2022a, b).

A mesial, distal, and labial periodontal probing must be used to determine the level of the epithelial attachment from the incisal edge of the tooth (Fig. 8.5). This will guide the dental professional to decide the location of the barrier. A coronal extension of the barrier to match the contour of the epithelial attachment (Fig. 8.6) has been proposed to increase the safety of the bleaching procedure by sealing a wider area against the leakage of peroxides to the periodontal tissues (Steiner and West 1994). ZOE-based materials, such as I.R.M. (Dentsply Sirona), and traditional glass-ionomer cements (GIC) are not currently recommended for the cervical barrier, as they do not completely prevent leakage of bleaching agents into the coronal part of the root canal (Rotstein et al. 1992b; Brighton et al. 1994).

The other two factors that affect dentin permeability are the pH and the presence of a smear layer. The pH of the paste left inside the pulp chamber is more acidic when the consistency is too liquid (Rotstein and Friedman 1991). Kehoe (1987) reported that the pH of dentin and cementum became more acidic after sealing the

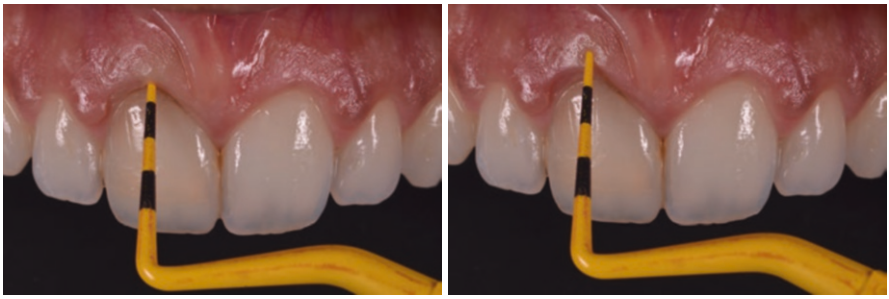


Fig. 8.5 A periodontal probe is used to determine the level of the epithelial attachment measuring from the incisal edge of the tooth. This will serve as a guide for placement of the root canal barrier

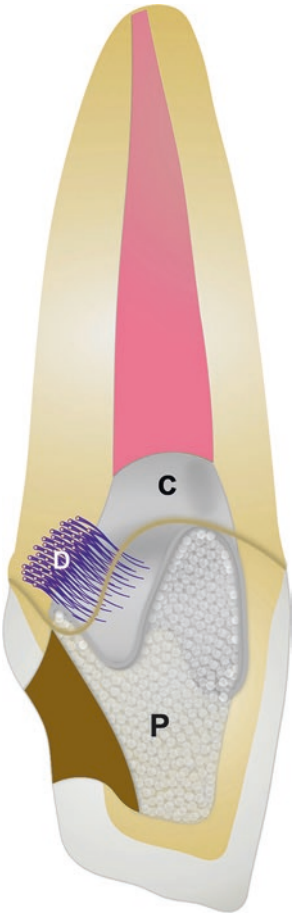


Fig. 8.6 Diagram depicting a coronal extension of the barrier that coronally matches the contour of the epithelial and increases the safety of the bleaching procedure by sealing a wider area against the leakage of peroxides to the periodontal tissues (adapted from Steiner and West 1994)*D* dentin tubules, *C* cervical barrier, *P* paste of sodium perborate and distilled water. *Courtesy of Dr. Andressa Ballarin and Dr. Guilherme Lopes*

walking-bleach material in the pulp space of root-filled teeth. Rotstein and Friedman (1991) reported that thick pastes used with the walking-bleach technique are alkaline, and their alkalinity increases with time. Initially, the pH of sodium perborate mixed with distilled water without dilution was 9.87, but it increased gradually to 10.70 during the following 14 days. The initial pH of sodium perborate mixed with Superoxol was 7.40, and it reached a value of 10.58 after 14 days. In both cases, a marked increase in pH occurred during the first 48 h. Accordingly, it is unlikely that EICR is caused by the acidity of current materials used for intracoronal bleaching. The use of sodium tetrahydrate mixed with water is recommended as a bleaching agent to reduce the risk of potential development of bleaching-related EICR (Weiger et al. 1994).

The removal of the smear layer from the dentin walls of the access cavity may increase the diffusion of the whitening agent through the dentinal tubules. Since there is a higher hydrogen peroxide diffusion when the access cavity is etched with phosphoric acid or rinsed with EDTA followed by NaOCl (Surapipongpuntr et al. 2008; Camps et al. 2010), it may be prudent to preserve the smear layer to decrease the risk of EICR (Camps et al. 2010). Hydrogen peroxide is a potent stimulator of

osteoclastic bone resorption. A significant increase in bone resorption was noted when rat osteoclasts, cultured on bovine cortical bone, were exposed to hydrogen peroxide (Bax et al. 1992). Some authors have suggested that bacteria in the gingival sulcus or in the pulp chamber may play a role in the root resorption process (Cvek and Lindvall 1985; Rotstein et al. 1991a; Heling et al. 1995). Hydrogen peroxide in high concentrations may increase bacterial penetration through dentinal tubules (Heling et al. 1995). This pathway for bacterial invasion may be a consequence of structural defects or pathological alterations of the cementum (Rotstein et al. 1991b).

Calcium hydroxide is effective in arresting external inflammatory root resorption and reducing the bacterial load inside the root canal space (Heithersay 1975). Several cases of bleaching-induced EICR have been treated successfully with intracoronal application of $Ca(OH)_2$ (Montgomery 1984; Gimlin and Schindler 1990). The pH increase in dental tissues after endodontic treatment with $Ca(OH)_2$ has a positive influence on the local environment of the resorption areas by decreasing osteoclastic activity and by stimulating the repair processes of the tissue (Tronstad et al. 1981). As dentinal tubules become wide open when resorption occurs, a communication between the pulp cavity and the periodontal tissues is formed. It has been proposed that $Ca(OH)_2$ placed in the pulp cavity penetrates the dentinal tubules to increase the pH in the root periphery and to promote repair (Tronstad et al. 1981). However, both $Ca(OH)_2$ paste and the resulting hydroxyl ions have been shown to diffuse poorly through dentin (Wang and Hume 1988; Fuss et al. 1989). Additionally, the therapy with $Ca(OH)_2$ was not capable of stopping the resorptive process in clinical cases of young patients treated with the walking-bleach technique (Goon et al. 1986; Latcham 1986; Friedman 1989). Bleaching-induced resorption in dogs was observed regardless of the presence of $Ca(OH)_2$, suggesting that *$Ca(OH)_2$ is unable to always prevent root resorption* associated with internal bleaching (Rotstein et al. 1991a).

8.6.2 Ankylosis

Ankylosis is a common outcome for the teeth with a history of avulsion or intrusion. Cvek and Lindvall (1985) followed up 11 maxillary incisors in 9 patients with radiographic evidence of post-intracoronal bleaching EICR. Ten teeth had a history of traumatic injury at ages 11–16 years. The bleaching treatment was performed in the affected teeth 12–90 months (mean of 48 months) after dental trauma. In five teeth, the root resorption was associated with ankylosis. It is possible that the compounding effect of the dental trauma and the chemical damage caused by the hydrogen peroxide exacerbated the replacement resorption or ankylosis.

8.6.3 Alterations in the Physical Properties of the Residual Tooth Structure

Intracoronal bleaching affects the mechanical and structural properties of dentin including ultimate tensile strength and dentin micromorphology. Cavalli et al. (2009) used sodium perborate, 35% carbamide peroxide, 25% hydrogen

peroxide, and 35% hydrogen peroxide. Bleaching was performed four times within a 72-h interval. Dentin ultimate strength was significantly higher for the control group, in which dentin was not bleached. More details on this topic are discussed in Chap. 4.

Superoxol mixed with sodium perborate increases the solubility of dentin and cementum. Rotstein et al. (1992a) concluded that 30% hydrogen peroxide might cause alteration in the chemical structure of the dentin and cementum, such as reduction of the organic component, making them more susceptible to degradation. Different intracoronal whitening agents affect dentin fracture strength (Carrasco-Guerisoli et al. 2009). Bovine teeth were subjected to several intracoronal bleaching techniques. Controls were treated with either sodium perborate mixed with 10% hydrogen peroxide or no bleaching agent. Whitening systems with a higher pH did not result in perceptible changes of dentin ultrastructure. Apparently, both low pH and hydrogen peroxide oxidation play a role in affecting the ultrastructure of dentin during internal dental bleaching. The use of alkaline products with reduced time of application may prevent such morphological alterations (Carrasco-Guerisoli et al. 2009). The effect of different bleaching agents was significant on the fracture resistance (Siavash Savadi Oskoee et al. 2018). In addition, restorative procedures using composite resin have been described to successfully restore the fracture resistance of bleached root-filled teeth (Roberto et al. 2012).

8.6.4 Decrease in Enamel and Dentin Bond Strength Immediately After Treatment

As described in Chap. 6, dentin and enamel bond strengths are significantly reduced in the teeth treated with bleaching agents. A delay in adhesive restorative procedures is recommended for root-filled teeth that are bleached internally, including bonding to calcium silicate-based materials (Sismanoglu et al. 2022). This is also recommended in cases in which a paste of sodium perborate with water is used without added hydrogen peroxide or carbamide peroxide. As mentioned earlier, a waiting period of at least 2 weeks after bleaching is recommended prior to performing adhesive restorations with resin-based composite in both enamel and dentin (Shinohara et al. 2005). Nonetheless, some patients may not be able to return for a subsequent appointment to have the access cavity restored with an adhesive technique. Since the access preparation will have to be restored immediately, the application of catalase Rotstein 1993 or sodium ascorbate (Lai et al. 2002) may be indicated in these cases. Rotstein (1993) reported that one application of catalase for 3 min following intracoronal whitening of nonvital teeth can eliminate the residual hydrogen peroxide from the pulp chamber and surrounding periodontal tissues. Lai et al. (2002) reported that bond strengths of two adhesives were reduced after bleaching, but the effect was reversed following the application of sodium ascorbate.

8.6.5 Chemical Burns of Soft Tissues

The application of catalase on the mucosa has a protective effect against the hydrogen peroxide-induced injury in animals (Rotstein et al. 1993b). Tipton et al. (1995) reported the in vitro ability of a concentration of catalase >20 U/mL to suppress the toxic effects of peroxide on mucosal fibroblasts. As described in Chap. 4, sodium bicarbonate may also be used to treat these chemical burns caused by hydrogen peroxide.

8.7 The Walking-Bleach Technique Step by Step

Figure 8.7 shows a diagram of a root-filled tooth (a) before the removal of the access cavity restoration and (b) after the bleaching paste is placed in the pulp chamber.

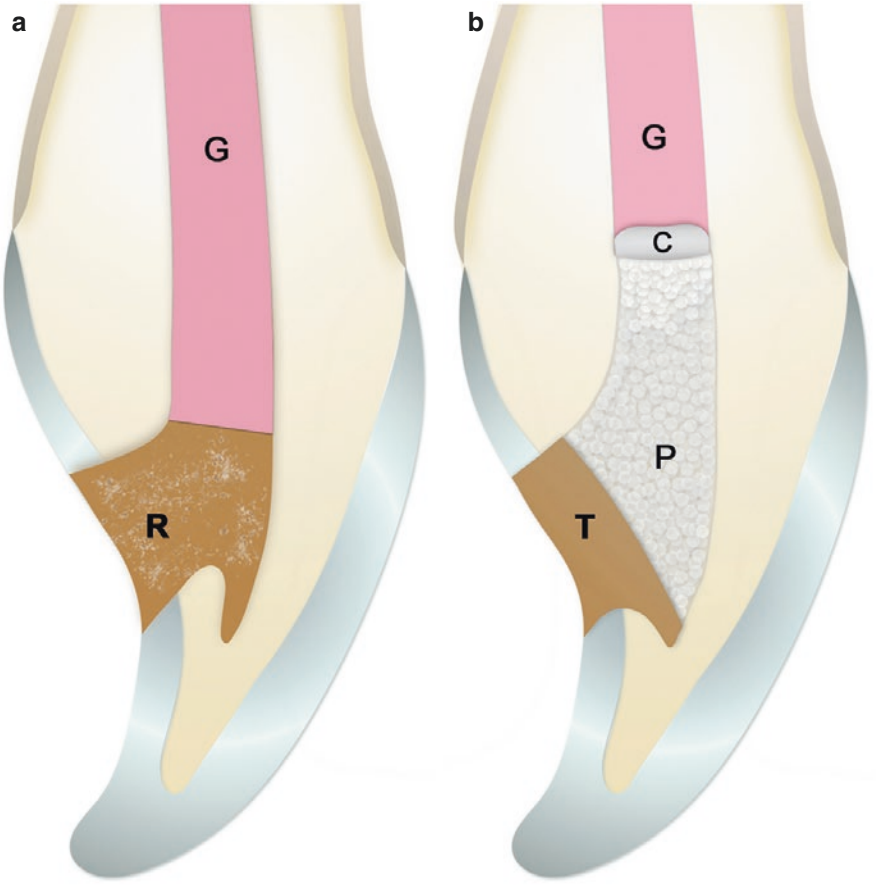
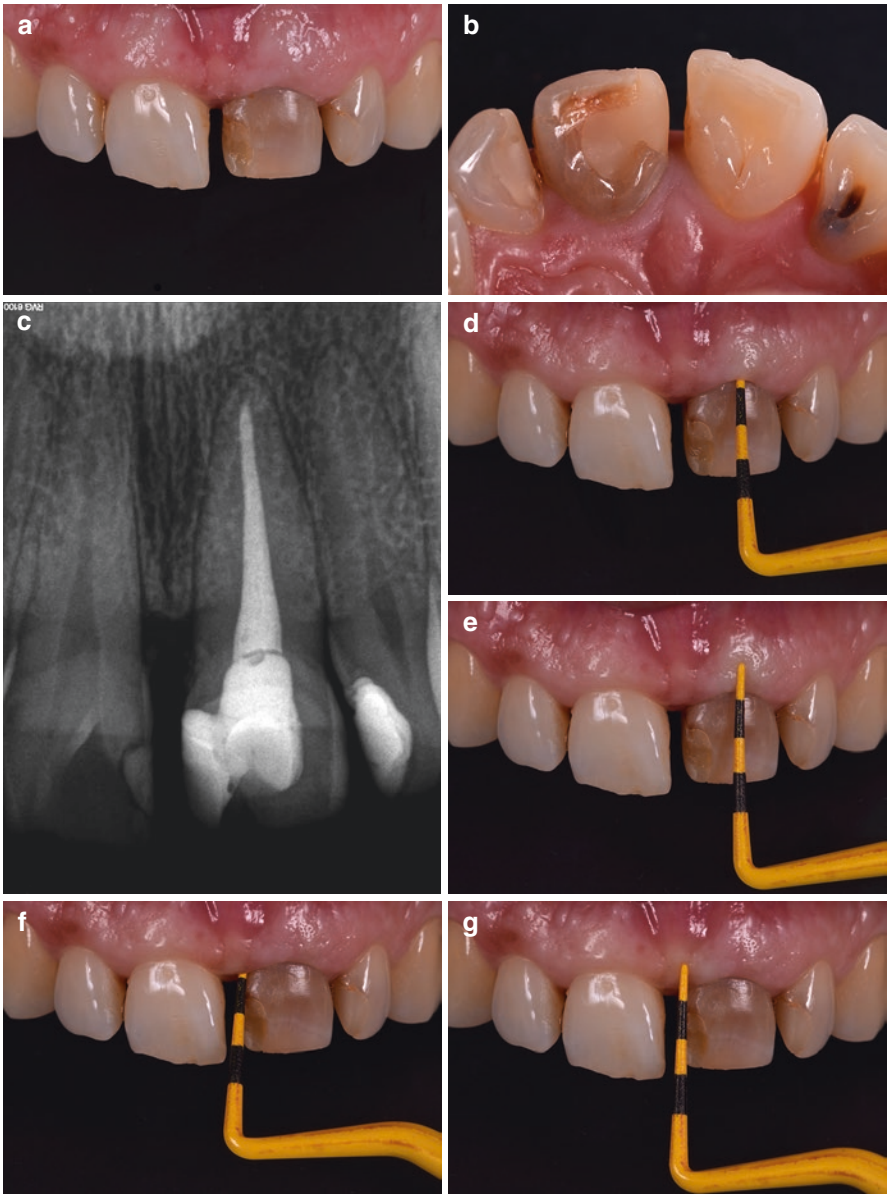


Fig. 8.7 Diagram of a root-filled tooth. (**a**) Before removal of the access cavity restoration and (**b**) after the bleaching paste is sealed in the pulp chamber. *G* gutta-percha, *R* restoration of the access cavity, *C* cervical barrier, *P* paste of sodium perborate and distilled water, *T* temporary restoration between walking-bleach sessions. *Courtesy of Dr. Andressa Ballarin and Dr. Guilherme Lopes*

Figure 8.8 includes a step-by-step clinical sequence of the walking-bleach technique.

1. Clinical and radiographic exam (Fig. 8.8a, b, c):
   (a) Determine the etiology of the discoloration, as some stains are more difficult to remove.
   (b) Check for defective coronal restorations that might have caused microleakage and subsequent internal discoloration. Defective restorations must be replaced temporarily to prevent the bleaching material from leaking into the mouth.
   (c) In case of active periodontitis, internal whitening is deferred, and the patient is referred to a specialist.
   (d) Evaluate the quality of the root canal treatment and status of periodontal/periapical tissues.
   (e) Do not perform internal bleaching if a periapical radiolucency is observed in the respective radiograph.
2. Inquire about the patient's expectations. Inform the number of sessions that may be needed and the respective limitations including the potential for color regression. Share with the patient the possibility that the color of intact teeth could not be attained.
3. Document the tooth color using dental photographs with a shade guide (Vita Classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter GmbH & Co. KG)). It is important to document the preoperative color for future reference.

Fig. 8.8 Clinical sequence of the walking-bleach technique. *Courtesy of Dr. George Gomes.* (**a**) Preoperative frontal view showing a gray/brown discoloration of tooth #9 (FDI 2.1). The patient mentioned that this tooth had been darker than the other teeth for at least 7 years. (**b**) Preoperative palatal (lingual) view. (**c**) Periapical radiograph. (**d**–**i**) Probing sequence to determine the level of epithelial attachment. (**j**) Isolation with rubber dam. (**k**) Removal of coronal restoration and any residual pulp tissue left in the pulp horns. (**l**) A periodontal probe is used to transfer the exact depth level for placement of the root canal barrier. (**m**) Lingual view of gutta-percha removal from the root canal cervical area using a System B heat plugger (Kerr Co.). (**n**) Frontal view of the System B heat plugger (Kerr Co.) showing the rubber stop reference corresponding to the same length shown in the periodontal probe of Fig. 8.8l. (**o**) A resin-modified glass ionomer material or RMGIC (Vitrebond Plus, 3M Oral Care) is applied into the root canal as a 2-mm-thick cervical barrier between the pulp chamber and the endodontic filling material. (**p**) The RMGIC material is light cured from the cavity access for 40 seconds. Any excess material must be removed with carbide bur in slow speed. (**q**) Sodium perborate is mixed with distilled water to a consistency of slightly moist sand and inserted into the pulp chamber with a plastic instrument or other suitable instrument. (**r**) The pulp chamber is filled with the bleaching paste short of the access cavo-surface margin. (**s**) Residual liquid is removed with dry cotton pellets by gently compressing the paste. A clearance of 1.5 mm is needed to insert a temporary restoration. (**t**) Reinforced ZOE cement (I.R.M. ZOE, Dentsply Sirona) is used as temporary restorative material. (**u**) Frontal view of tooth #9 (FDI 2.1) immediately after removing the rubber dam. The tooth is apparently lighter because of dehydration. (**v**) Frontal view of tooth #9 (FDI 2.1) at the beginning of the second walking-bleach session. (**w**) Frontal view of tooth #9 (FDI 2.1) after three walking-bleach sessions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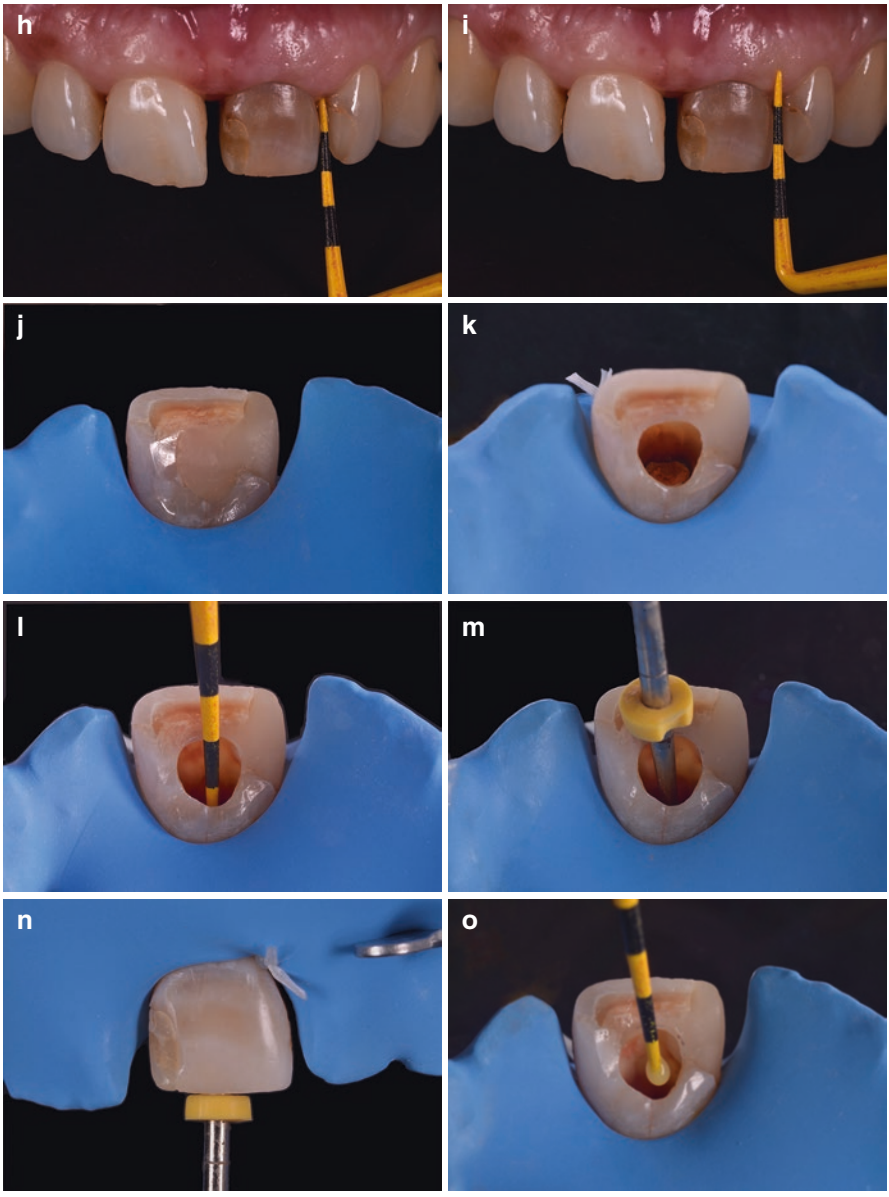

Fig. 8.8 (continued)

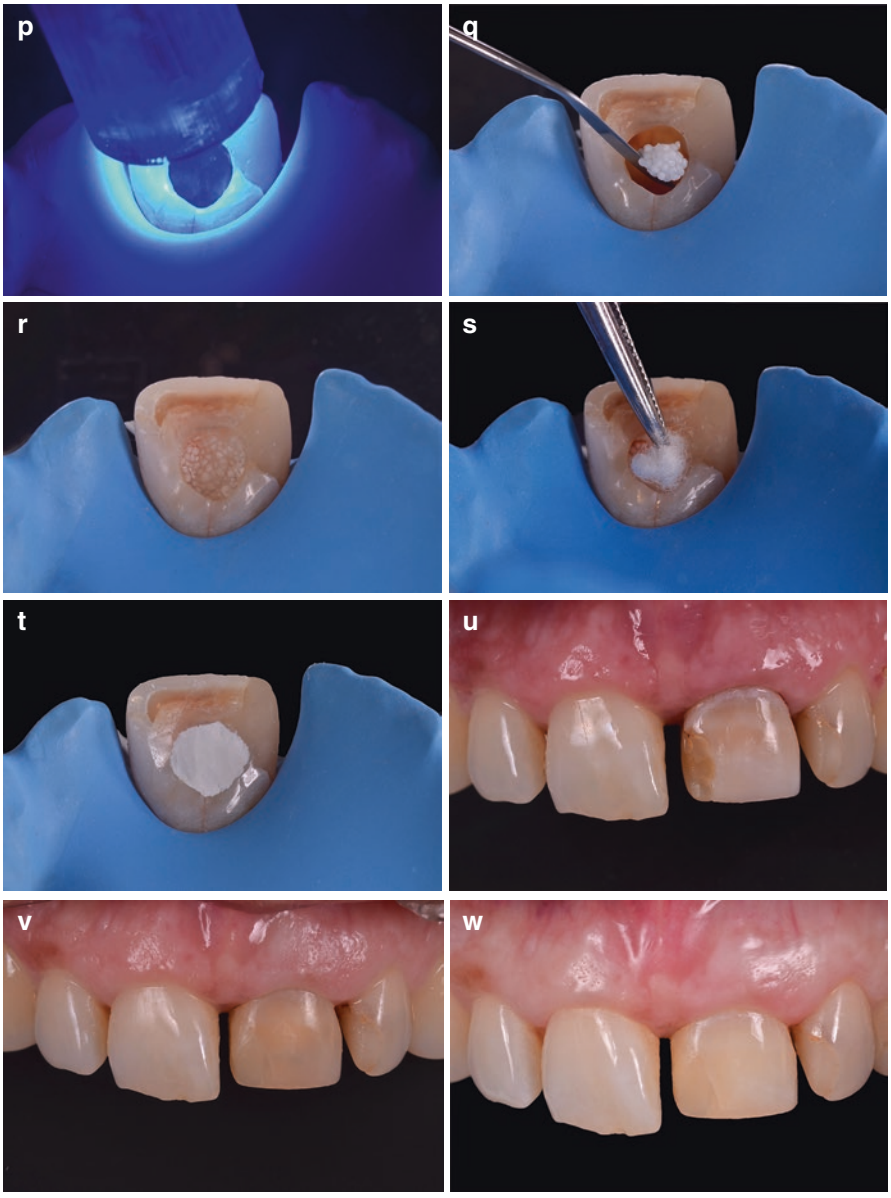

Fig. 8.8 (continued)

4. Rubber dam isolation and sealing of the gingival margin and papilla are required (OpalDam, Ultradent Products, Inc., South Jordan, UT, USA; or Top Dam, FGM Dental Group, Fort Lauderdale, FL, USA).
5. A periodontal probe is used to determine the level of the epithelial attachment from the incisal edge of the tooth. This measurement must include the interproximal areas (Fig. 8.8d–i). and will serve as a guide for placement of the root canal barrier.
6. The restorative material is removed from the pulp chamber (Fig. 8.8j, k). The angulation of the bur must be parallel to the long axis of the anterior tooth being bleached. Often inexperienced clinicians remove the materials from the access preparation with the bur toward the facial aspect of the tooth (Fig. 8.9), which results in inadvertent removal of sound dentin (in rare cases the dentin structure on the buccal aspect is heavily discolored and must be carefully removed in slow speed to avoid perforation). We recommend the use of ultrasonic tips under refrigeration.

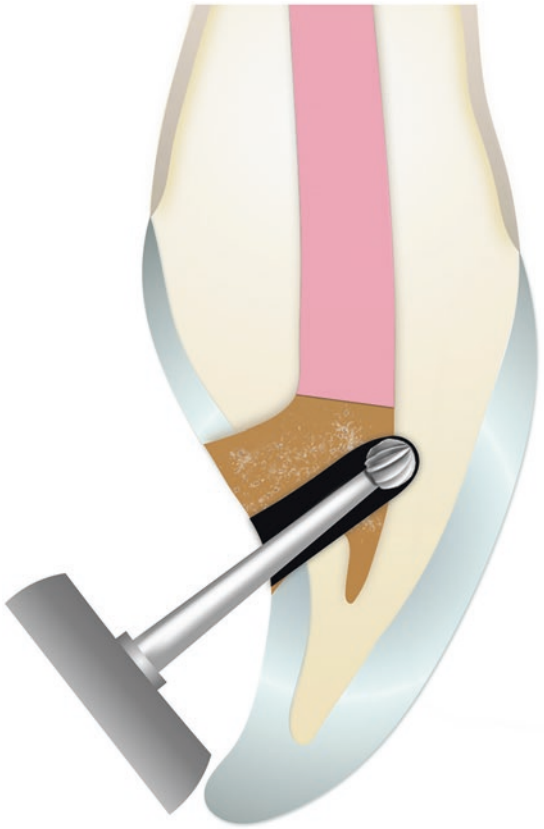

Fig. 8.9 Clinicians must be careful when removing the restorative materials from the access preparation of the anterior teeth to avoid removing sound tooth structure from the buccal aspect causing enamel perforation. *Courtesy of Dr. Andressa Ballarin and Dr. Guilherme Lopes*

7. At this stage it is crucial to check for residual discolored pulp tissue in the pulp horns. This tissue must be removed.
8. A periodontal probe is used to transfer the exact depth level for placement of the root canal barrier using the reference measured before (Fig. 8.8l).
9. The root canal obturation material is removed from the cervical area of the root (Fig. 8.8m, n), using a System B heat plugger (Kerr Co., Brea, CA, USA) or a Peeso reamer. A 2-mm-thick layer of a resin-modified glass ionomer material (RMGIC) (Fig. 8.8o) is then inserted as a root canal barrier (Fig. 8.7). A zinc polycarboxylate cement may also be used as both materials bond chemically to dentin. Ideally the cervical barrier should match the contour of the epithelial attachment, as proposed by Steiner and West (1994) (Fig. 8.6). The RMGIC material is light cured from the cavity access for at least 40 seconds (Fig. 8.8p). Any excess material must be removed with carbide burs using slow speed.
10. Sodium perborate is mixed with distilled water (anesthetic solution and saline have also been used) to a consistency of slightly moist sand. This mix must possess enough consistency to be inserted into the pulp chamber with a plastic instrument (Fig. 8.8q) or plugged with an amalgam carrier. In case the mix is too runny, it is extremely difficult to insert it adequately into the pulp chamber. Once the paste is in the pulp chamber (Fig. 8.8r), residual liquid is removed with dry cotton pellets by gently compressing the mixture (Fig. 8.8s).
11. A clearance of at least 1.5 mm is needed to insert a temporary restoration into the access cavity. The area must be gently air-dried; otherwise, the restorative material will dislodge easily. Some clinicians use Cavit (3M Oral Care, St. Paul, MN, USA) as the temporary restorative material, but it may dissolve in the mouth and result in an open access cavity. Reinforced zinc oxide eugenol (ZOE) cement I.R.M. ZOE (Dentsply Sirona) (Fig. 8.8t) is recommended. Another temporary restorative technique involves the use of a temporary low-viscosity resin-based material without an intermediate adhesive after acid etching enamel. This will provide a short-term efficient seal and micromechanical retention. After removing the rubber dam, the tooth is often dehydrated (Fig. 8.8u).
12. The patient is informed of the need to return for a subsequent appointment in 1 week to possibly repeat the procedure and 2 weeks thereafter (Fig. 8.8v, w). Our experience is that alternative options may have to be considered when results of intracoronal whitening are not acceptable after the third internal bleaching session.
13. A waiting period of at least 2 weeks after the conclusion of the bleaching treatment is recommended prior to performing the definitive adhesive restorations with composite.

8.8 Summary

Internal whitening of root-filled teeth is a noninvasive and good esthetic resource compared to full-coverage restorations. Patients must be informed that the chance of color relapse is greater than 25% and that data on long-term outcomes is limited. EICR and ankylosis seem to occur more frequently in the teeth that were exposed to traumatic injury and were bleached. The placement of cervical barriers to reduce the dentinal permeability at the CEJ level and reduce the diffusion of hydrogen peroxide to the periodontal ligament is recommended.

References

Abbott P, Heah SY (2009) Internal bleaching of teeth: an analysis of 255 teeth. Aust Dent J 54:326–333

Abou-Rass M (1988) Long-term prognosis of intentional endodontics and internal bleaching of tetracycline-stained teeth. Compend Contin Educ Dent 19:1034–1038, 1040-2, 1044

Ahmed HMA, Abbott PV (2012) Discolouration potential of endodontic procedures and materials: a review. Int Endod J 45:883–897

Aldecoa EA, Mayordomo FG (1992) Modified internal bleaching of severe tetracycline discoloration: a 6-year clinical evaluation. Quintessence Int 23:83–89

Amato M, Scaravilli MS, Farella M, Riccitiello F (2006) Bleaching teeth treated endodontically: long-term evaluation of a case series. J Endod 32:376–378

Anitua E, Zabalegui B, Gil J, Gascon F (1990) Internal bleaching of severe tetracycline discolorations: four-year clinical evaluation. Quintessence Int 21:783–788

Arens D (1989) The role of bleaching in esthetics. Dent Clin N Am 33:319–336

Attin T, Paqué F, Ajam F, Lennon AM (2003) Review of the current status of tooth whitening with the walking bleach technique. Int Endod J 36:313–329

Bax BE, Alam AS, Banerji B, Bax CM, Bevis PJ, Stevens CR, Moonga BS, Blake DR, Zaidi M (1992) Stimulation of osteoclastic bone resorption by hydrogen peroxide. Biochem Biophys Res Commun 183:1153–1158

Bersezio C, Sánchez F, Estay J, Ledezma P, Vernal R, Garlet G, Oliveira OB, Fernández E (2020) Inflammatory markers IL-1β and RANK-L assessment after non-vital bleaching: a 3-month follow-up. J Esthet Restor Dent 32:119–126

Bizhang M, Heiden A, Blunck U, Zimmer S, Seemann R, Roulet JF (2003) Intracoronal bleaching of discolored non-vital teeth. Oper Dent 28:334–340

Boksman L, Jordan RE, Skinner DH (1983) Non-vital bleaching – internal and external. Austr Dent J 28:149–152

Brighton DM, Harrington GW, Nicholls JI (1994) Intracanal isolating barriers as they relate to bleaching. J Endod 20:228–232

Brown G (1965) Factors influencing successful bleaching of the discolored root-filled tooth. Oral Surg Oral Med Oral Pathol 20:238–244

Camps J, de Franceschi H, Idir F, Roland C, About I (2007) Time-course diffusion of hydrogen peroxide through human dentin: clinical significance for young tooth internal bleaching. J Endod 33:455–459

Camps J, Pommel L, Aubut V, About I (2010) Influence of acid etching on hydrogen peroxide diffusion through human dentin. Am J Dent 23:168–170

Carrasco-Guerisoli LD, Schiavoni RJ, Barroso JM, Guerisoli DM, Pecora JD, Froner IC (2009) Effect of different bleaching systems on the ultrastructure of bovine dentin. Dent Traumatol 25:176–180

Carrillo A, Arredondo Trevino MV, Haywood VB (1988) Simultaneous bleaching of vital teeth and an open chamber nonvital tooth with 10% carbamide peroxide. Quintessence Int 29:643–648
Cavalli V, Shinohara MS, Ambrose W, Malafaia FM, Pereira PN, Giannini M (2009) Influence of intracoronal bleaching agents on the ultimate strength and ultrastructure morphology of den tine. Int Endod J 42:568–575
Coelho AS, Garrido L, Mota M, Marto CM, Amaro I, Carrilho E, Paula A (2020) Non-vital tooth bleaching techniques: a systematic review. Coatings 10:61
Costas FL, Wong M (1991) Intracoronal isolating barriers: effect of location on root leakage and effectiveness of bleaching agents. J Endod 17:365–368
Cvek M, Lindvall A-M (1985) External root resorption following bleaching of pulpless teeth with oxygen peroxide. Endod Dent Traumatol 1:56–60
Dabbagh B, Alvaro E, Vu DD, Rizkallah J, Schwartz S (2002) Clinical complications in the revascularization of immature necrotic permanent teeth. Pediatr Dent 34:414–417
de Souza-Zaroni WC, Lopes EB, Ciccone-Nogueira JC, Silva RC (2009) Clinical comparison between the bleaching efficacy of 37% peroxide carbamide gel mixed with sodium perborate with established intracoronal bleaching agent. Oral Surg Oral Med Oral Pathol 107:e43–e47
Dietz VH (1957) The bleaching of discolored teeth. Dent Clin N Am 1:897–902
Feiglin B (1987) A 6 year recall study of clinically chemically bleached teeth. Oral Surg Oral Med Oral Pathol 63:610–613
Fischer G (1911) The bleaching of discolored teeth with H_2O_2. Dent Cosmos 53:246–247
Frank A, Kanzow P, Rodig T, Wiegand A (2022) Comparison of the bleaching efficacy of different agents used for internal bleaching: a systematic review and meta-analysis. J Endod 48:171–178
Freccia WF, Peters DD, Lorton L, Bernier WE (1982) An in vitro comparison of nonvital bleaching techniques in the discolored tooth. J Endod 8:70–77
Friedman S (1989) Surgical-restorative treatment of bleaching related external root resorption. Endod Dent Traumatol 5:63–67
Friedman S, Rotstein I, Libfield H, Stabholz A, Heling I (1988) Incidence of external root resorption and esthetic results in 58 bleached pulpless teeth. Endod Dent Traumatol 4:23–26
Fuss Z, Szajkis S, Tagger M (1989) Tubular permeability to calcium hydroxide and to bleaching agents. J Endod 15:362–364
Gimlin DR, Schindler G (1990) The management of post bleaching cervical resorption. J Endod 16:292–297
Glockner K, Hulla H, Ebeleseder K, Städtler P (1999) Five-year follow-up of internal bleaching. Braz Dent J 10:105–110
Goon WW, Cohen S, Borer RF (1986) External cervical root resorption following bleaching. J Endod 112:414–418
Greenwall-Cohen J, Greenwall L, Haywood V, Harley K (2018) Tooth whitening for the under-18-year-old patient. Br Dent J 225:19–26
Harlan AW (1884) The removal of stain from the teeth caused by administration of medicinal agents and the bleaching of pulpless teeth. Am J Dent Sci 20:1884–1885
Harrington GW, Natkin E (1979) External resorption associated with bleaching of pulpless teeth. J Endod 5:344–348
Hattab FN, Qudeimat MA, al-Rimawi HS (1999) Dental discoloration: an overview. J Esthet Dent 11:291–310
He S, Goerig AC (1989) An in vitro comparison of different bleaching agents in the discolored tooth. J Endod 15:106–111
Heithersay GS (1975) Calcium hydroxide in the treatment of pulpless teeth with associated pathology. J Br Endod Soc 8:74–93
Heithersay GS, Dahlstrom SW, Marin PD (1994) Incidence of invasive cervical resorption in bleached root-filled teeth. Austr Dent J 39:82–87
Heling I, Parson A, Rotstein I (1995) Effect of bleaching agents on dentin permeability to Streptococcus faecalis. J Endod 21:540–542
Holmstrup G, Palm AM, Lambjerg-Hansen H (1988) Bleaching of discoloured root-filled teeth. Endod Dent Traumatol 4:197–201

Howell RA (1981) The prognosis of bleached root-filled teeth. Int Endod J 14:22–26
Irusa K, Alrahaem IA, Ngoc CN, Donovan T (2022) Tooth whitening procedures: a narrative review. Dent Rev 2:100055
Jang JH, Kang M, Ahn S, Kim S, Kim W, Kim Y, Kim E (2013) Tooth discoloration after the use of new pozzolan cement (Endocem) and mineral trioxide aggregate and the effects of internal bleaching. J Endod 39:1598–1602
Jimenez-Padilla J, Benavides-Reyes C, Viqueira-Perez V, Martinez Verdu F, Bolaños M, Gonzalez-Lopez S (2022) Effect of internal bleaching on the reversal of coronal discoloration induced by triple-antibiotic-paste or biodentine in regenerative endodontic procedures. Color Res Appl 47:518–527
Kahler B (2022a) Present status and future directions – managing discoloured teeth. Int Endod J 2022(00):1–29
Kahler B (2022b) Present status and future directions - managing discoloured teeth. Int Endod J 55(Suppl 4):922–950
Kang SH, Shin YS, Lee HS, Kim SO, Shin Y, Jung IY, Song JS (2015) Color changes of teeth after treatment with various mineral trioxide aggregate based materials: an ex-vivo study. J Endod 41:737–741
Kashima-Tanaka M, Tsujimoto Y, Kawamoto K, Senda N, Ito K, Yamazaki M (2003) Generation of free radicals and/or active oxygen by light or laser irradiation of hydrogen peroxide or sodium hypochlorite. J Endod 29:141–143
Kehoe JC (1987) pH reversal following in vitro bleaching of pulpless teeth. J Endod 13:6–9
Keskin C, Demiryurek E, Ozyurek T (2015) Color stabilities of calcium silicate-based materials in contact with different irrigation solutions. J Endod 41:409–411
Kim JH, Kim Y, Shin SJ, Park JW, Jung IY (2010) Tooth discoloration of immature permanent incisor associated with triple antibiotic therapy: a case report. J Endod 36:1086–1091
Kingsbury CA (1861) Discoloration of dentine. Dent Cosmos 3:57–60
Kirchhoff AL, Raldi DP, Salles AC, Cunha RS, Mello I (2015) Tooth discoloration and internal bleaching after the use of triple antibiotic paste. Int Endod J 48:1181–1187
Kohli MR, Yamaguchi M, Setzer F, Karabucak B (2015) Spectrophotometric analysis of coronal tooth discoloration induced by various bioceramic cements and other endodontic materials. J Endod 41:1862–1866
Kwon SR (2011) Whitening the single discolored tooth. Dent Clin N Am 55:229–239
Lado EA, Stanley HR, Weisman MI (1983) Cervical resorption in bleached teeth. Oral Surg Oral Med Oral Pathol 55:78–80
Lai SC, Tay FR, Cheung GS, Mak YF, Carvalho RM, Wei SH, Toledano M, Osorio R, Pashley DH (2002) Reversal of compromised bonding in bleached enamel. J Dent Res 81:477–481
Latcham NL (1986) Post bleaching cervical resorption. J Endod 12:262–264 Leuschner U (2003) primary biliary cirrhosis – presentation and diagnosis. Clin Liver Dis 7:741–758
Li Q, Xu BT, Li R, Yu H, Wang YN (2010) Quantitative evaluation of colour regression and mineral content change of bleached teeth. J Dent 38:253–260
Lise DP, Siedschlag G, Bernardon JK, Baratieri LN (2018) Randomized clinical trial of 2 non vital tooth bleaching techniques: a 1-year follow up. J Prosthet Dent 119:53–59
Madison S, Walton R (1990) Cervical root resorption following bleaching of endodontically treated teeth. J Endod 16:570–574
Marciano MA, Duart MAH, Camilleri J (2015) Dental discoloration caused by bismuth oxide in MTA in the presence of sodium hypochlorite. Clin Oral Investig 19:2201–2209
Miller HC (1903) Bleaching teeth. Dent Cosmos 45:112–114
Montgomery S (1984) External cervical resorption after bleaching a pulpless tooth. Oral Surg Oral Med Oral Pathol 57:203–206
Możyńska J, Metlerski M, Lipski M, Nowicka A (2017) Tooth discoloration induced by different calcium silicate-based cements: a systematic review of in vitro studies. J Endod 43:1593–1601
Newton R, Hayes J (2020) The association of external cervical resorption with modern internal bleaching protocols: what is the current evidence? Br Dent J 228:333–337

Nutting EB, Poe GS (1967) Chemical bleaching of discolored endodontically treated teeth. Dent Clin North Am 11:655–662
Oskoee SS, Bahari M, Daneshpooy M, Ajami AA, Rahbar M (2018) Effect of different Intraorifice barriers and bleaching agents on the fracture resistance of Endodontically treated anterior teeth. J Endod 44:1731–1735
Patel S, Kanagasingam S, Pitt Ford T (2009) External cervical resorption: a review. J Endod 35:616–625
Petrino JA, Boda K, Shambarger S, Bowles W, McClanahan SB (2010) Changes in regenerative endodontics. J Endod 36:536–541
Plotino G, Buono L, Grande NM, Pameijer CH, Somma F (2008) Non-vital tooth bleaching: a review of the literature and clinical procedures. J Endod 34:394–407
Prinz H (1924) Recent improvements in tooth bleaching. A clinical syllabus. Dent Cosmos 66:558–560
Rezende M, Loguercio AD, Kossatz S, Reis A (2016) Predictive factors on the efficacy and risk/intensity of tooth sensitivity of dental bleaching: a multi regression and logistic analysis. J Dent 45:1–6
Roberto AR, Sousa-Neto MD, Viapiana R, Giovani AR, Souza Filho CB, Paulino SM, Silva-Sousa YT (2012) Effect of different restorative procedures on the fracture resistance of teeth submitted to internal bleaching. Braz Oral Res 26:77–82
Rotstein I (1993) Role of catalase in the elimination of residual hydrogen peroxide following tooth bleaching. J Endod 19:567–569
Rotstein I, Friedman S (1991) pH variation among materials used for intracoronal bleaching. J Endod 17:376–379
Rotstein I, Friedman S, Mor C, Katznelson J, Sommer M, Bab I (1991a) Histological characterization of bleaching-induced external root resorption in dogs. J Endod 17:436–441
Rotstein I, Torek Y, Misgav R (1991b) Effect of cementum defects on radicular penetration of 30% H_2O_2 during intracoronal bleaching. J Endod 17:230–233
Rotstein I, Zalkind M, Mor C, Tarabeah A, Friedman S (1991c) In vitro efficacy of sodium perborate preparations used for intracoronal bleaching of discolored non-vital teeth. Endod Dent Traumatol 7:177–180
Rotstein I, Lehr Z, Gedalia I (1992a) Effect of bleaching agents on inorganic components of human dentin and cementum. J Endod 18:290–293
Rotstein I, Zyskind D, Lewinstein I, Bamberger N (1992b) Effect of different protective base materials on hydrogen peroxide leakage during intracoronal bleaching in vitro. J Endod 18:114–117
Rotstein I, Mor C, Friedman S (1993a) Prognosis of intracoronal bleaching with sodium perborate preparations in vitro: 1-year study. J Endod 19:10–12
Rotstein I, Wesselink PR, Bab I (1993b) Catalase protection against hydrogen peroxide-induced injury in rat oral mucosa. Oral Surg Oral Med Oral Pathol 75:744–750
Salvas JC (1938) Perborate as a bleaching agent. J Am Dent Assoc 25:324
Settembrini L, Gultz J, Kaim J, Scherer W (1997) A technique for bleaching nonvital teeth: inside/outside bleaching. J Am Dent Assoc 128:1283–1284
Sherwood IA (2010) Fluorosis varied treatment options. J Conserv Dent 13:47–53
Shinohara MS, Peris AR, Pimenta LA, Ambrosano GM (2005) Shear bond strength evaluation of composite resin on enamel and dentin after nonvital bleaching. J Esthet Restor Dent 17:22–29
Şişmanoğlu S (2020) Bleaching of nonvital teeth: a review. Aurum J Health Sc 2:91–114
Sismanoglu S, Yildirim-Bilmez Z, Gurcan AT, Gumustas B, Taysi M, Berkman M (2022) Influence of intracoronal bleaching agents on the bond strength of MTA cements to composite resin and their surface morphology. Odontology 110:148–156
Spasser HF (1961) A simple bleaching technique using sodium perborate. N Y State Dent J 27:332–334
Steiner DR, West JD (1994) A method to determine the location and shape of an intracoronal bleach barrier. J Endod 20:304–306
Surapipongpuntr P, Duangcharee W, Kwangsamai S, Ekka A (2008) Effect of root canal irrigants on cervical dentine permeability to hydrogen peroxide. Int Endod J 41:821–827

Swift EJ Jr (2012) Critical appraisal. Reversal of compromised bonding after bleaching. J Esthet Restor Dent 24:357–361
Tipton DA, Braxton SD, Dabbous MK (1995) Effects of a bleaching agent on human gingival fibroblasts. J Periodontol 66:7–13
Tronstad L, Andreasen JO, Hasselgren G, Kristerson L, Riis I (1981) pH changes in dental tissues after root canal filling with calcium hydroxide. J Endod 7:17–21
Vachon C, Vanek P, Friedman S (1998) Internal bleaching with 10% carbamide peroxide in vitro. Pract Periodontics Aesthet Dent 10:1145–1148, 1150, 1152
Valko M, Leibfritz D, Moncol J, Cronin MT, Mazur M, Telser J (2007) Free radicals and antioxidants in normal physiological functions and human disease. Int J Biochem Cell Biol 39:44–84
van der Burgt TP, Plasschaert AJ (1985) Tooth discoloration induced by dental materials. Oral Surg Oral Med Oral Pathol 60:666–669
van der Burgt TP, Plasschaert AJ (1986) Bleaching of tooth discoloration caused by endodontic sealers. J Endod 12:231–234
van der Burgt TP, Eronat C, Plasschaert AJ (1986) Staining patterns in teeth discolored by endodontic sealers. J Endod 12:187–191
Venkataraman M, Singhal S, Tikku AP, Chandra A (2019) Comparative analysis of tooth discoloration induced by conventional and modified triple antibiotic pastes used in regenerative endodontics. Indian J Dent Res 30:933–936
Wang JD, Hume WR (1988) Diffusion of hydrogen ion and hydroxyl ion from various sources through dentine. Int Endod J 21:17–26
Weiger R, Kuhn A, Löst C (1994) Radicular penetration of hydrogen peroxide during intra-coronal bleaching with various forms of sodium perborate. Int Endod J 27:313–317
Weisman MI (1963) Efficient bleaching procedure for the pulpless tooth. Dent Dig 69:347–352
Wiegand A, Drebenstedt S, Roos M, Magalhães AC, Attin T (2008). 12-month color 12:303-10

Part III

Improvement of Tooth Color with Enamel Etching Techniques

9 Enamel Microabrasion for the Removal of Superficial Coloration and Surface Texture Defects

Kevin J. Donly and Theodore P. Croll

Abstract

Enamel microabrasion has become a routine clinical procedure in dentistry. It includes a low concentration of hydrochloric acid (6%–9%) and silicon carbide abrasive powder in a silica gel, for rotary application. Successful microabrasion removes an insignificant and unrecognizable amount of surface enamel and renders the surface more resistant to demineralization. Enamel microabrasion has proven to be a very useful adjunctive or alternative treatment in esthetic dentistry.

9.1 Introduction

In the early 1900s, Dr. Walter Kane used muriatic (hydrochloric) acid to erode endemic brown and white fluorosis discoloration from the anterior teeth of people in Colorado. Forty-four-year postoperative results of one of those patients (E. E.G.) were pictured in an article by Dr. Robert McCloskey, published in the Journal of the American Dental Association (McCloskey 1984). She had been treated in 1926 as a 16-year-old. Sixty years after Dr. Kane's treatment (1986), the same patient was photographed, then 76 years old (Fig. 9.1) (Croll 1987). A stark difference was noted in the appearance of her incisors and canine teeth, compared to the untreated posterior teeth. Some considered Dr. Kane's method a type of dental bleaching, but

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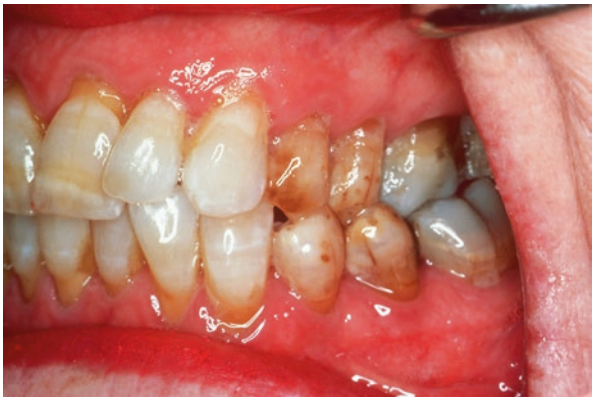

Fig. 9.1 60-year results of eliminating brown fluorosis stain using hydrochloric acid. Anterior teeth treated, posterior teeth untreated

actually, the hydrochloric acid was dissolving the outermost layer of enamel that contained the unsightly brown and white discoloration. As evidenced by the 60-year postoperative view, the amount of enamel lost in treatment was unrecognizable and of no long-term consequence (Fig. 9.1). E. E.G. reported that her "upper and lower front teeth" (anterior) were treated by Dr. Kane, and "the teeth in back" (premolars and molars) were not. She also remembered that Dr. Kane had warmed the teeth with careful application of a flame, using a small torch. She did not recall any discomfort from that. The results, as seen in the photograph, are dramatic, and the treated teeth give a much better appearance than those not "color-corrected" with Dr. Kane's muriatic acid/heat method.

Croll used a combination of 18% hydrochloric acid mixed with fine grit laboratory pumice with the idea that combining chemical erosion with mechanical abrasion would also reduce the enamel surface microscopically, but more rapidly, and with the clinician in control. In 1986, Croll and Cavanaugh first reported this type of approach and termed the treatment "enamel microabrasion" (EM) (Croll and Cavanaugh 1986a, b). After much more experience, a textbook followed (Croll 1991).

Enamel microabrasion is analogous to dermabrasion on skin surfaces. It represents a most conservative method of removing intrinsic, yet superficial, enamel dysmineralization (ibid, pg 22), decalcification, and texture defects avoiding the need for restorative masking with artificial materials such as bonded resin-based composite or bonded porcelain veneers. Successful microabrasion removes an insignificant and unrecognizable amount of surface enamel and, with it, the offending discolored or "maltextured" layer. Oftentimes enamel microabrasion can be combined with dental bleaching (Haywood and Heymann 1989) for optimum enhancement of tooth appearance (Cvitko et al. 1992; Croll 1992, 1998; Killian 1993).

Enamel microabrasion has become a routine clinical procedure in dentistry (ADA treatment code D9970), and commercial microabrasion products (PREMA, Premier Dental Products, Plymouth Meeting, PA, and OPALUSTRE, Ultradent Products, South Jordan, UT) are available to facilitate treatment. These products contain a low concentration of hydrochloric acid (6–9%) and silicon carbide abrasive powder in a silica gel, for rotary application. Research has shown that use of

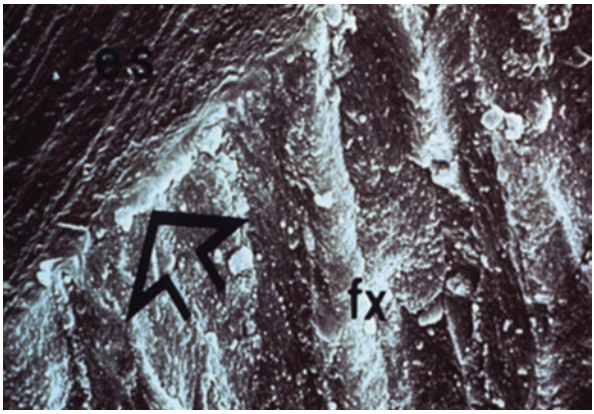

Fig. 9.2 A scanning electron microscopic view of the polished enamel surface following microabrasion and the natural appearance of enamel below the polished surface in this fractured (fx) enamel specimen

these products followed by natural remineralization creates a lustrous enamel surface that not only is more resistant to acid challenge but also accumulates less dental plaque than untreated surfaces (Segura et al. 1997a, b). Polarized light microscope and scanning electron microscope studies have revealed that microabrasion results in an enamel surface with a superficial layer of compacted, aprismatic mineral that gives a glass-like clinical appearance. The microabrasion technique removes some surface enamel but also packs some of the abraded calcium and phosphate into the interprismatic spaces to create a highly dense and polished surface (Fig. 9.2) (Berg and Donly 1991; Donly et al. 1992). Combining mechanical abrasion and chemical erosion inspired the terms "abrosion effect" (Donly et al. 1992) and its result, the "enamel glaze."

9.2 Enamel Microabrasion Procedure

The enamel microabrasion procedure can be outlined as follows:

1. Determination is made whether the tooth discoloration or texture defect is relatively superficial. Enamel microabrasion is not indicated for tooth discolorations such as seen with tetracycline dentinal stain, dentinogenesis imperfecta, and deep enamel hypoplastic or hypocalcification defects. EM treatment is indicated for enamel dysmineralization discolorations such as seen with brown and white fluorosis, idiopathic brown or white stain, or superficial enamel texture anomalies.
2. Pretreatment photographs are always advised, both for medicolegal considerations and for education of the patient and parents.
3. Local anesthesia is used only if needed to facilitate rubber dam placement.
4. Rubber dam application or isolation with OpalDam® or OpalDam Green® (Ultradent Products, South Jordan, UT) is recommended. Protective eyewear for the patient is mandatory.

5. To hasten treatment results, a cylindrical diamond bur can be used at slow speed, to initiate enamel surface microreduction (Croll 1993).
6. Using either PREMA® Enamel Microabrasion Compound with rotary polishing cups or OPALUSTRE® with OpalCups™, a small portion of slurry is applied to the tooth surface. A high torque gear-reduction handpiece can be used, but with careful application, to avoid splattering, and treatment can be achieved safely with a standard slow-speed angle. After 5–10 s, using moderate pressure, the microabrasion compound is rinsed with water, and results are immediately observed.
7. Five 10-s applications are repeated until the coloration defect is eliminated. Determination of tooth appearance should be made while the tooth is wet.
8. After completion of microabrasion, the treated teeth should be saturated for several minutes with a fluoride-containing gel.

9.3 Representative Cases

Enamel microabrasion treatment of three patients is documented below. One had decalcification (Croll and Bullock 1994); another, enamel dysmineralization; and the third, congenital enamel texture malformation (Killian and Croll 1990). A fourth case is shown with 27-year postoperative enamel microabrasion results combined with tooth bleaching in the adult years.

9.3.1 Case One

A 16-year-old boy had white decalcification markings in the gingival half of his maxillary anterior teeth, related to inadequate oral hygiene during his orthodontic therapy (Figs. 9.3a–d). There was a caries lesion associated with the decalcification on the maxillary left canine tooth (Fig. 9.3b). The maxillary premolars also had facial decalcification spots. A small shear fracture was noted on the maxillary left first premolar, perhaps occurring during orthodontic bracket removal (Fig. 9.3b). That fractured region was smoothed with a fine-tipped diamond bur. White decalcification areas were seen on some mandibular teeth also, but none were noticeable when the patient spoke or smiled, and none had associated caries.

Treatment is shown in Figs. 9.3a–d.

9.3.2 Case Two

A ten-year-old boy had white and brown idiopathic white and brown dysmineralization, chiefly of the labial surfaces of the maxillary central incisors (Fig. 9.4a). The cause of the white and brown dysmineralization could have been too much systemic fluoride in the years of amelogenesis, but the permanent first molars were not affected, and the parents could not identify a source of excess fluoride in the child's

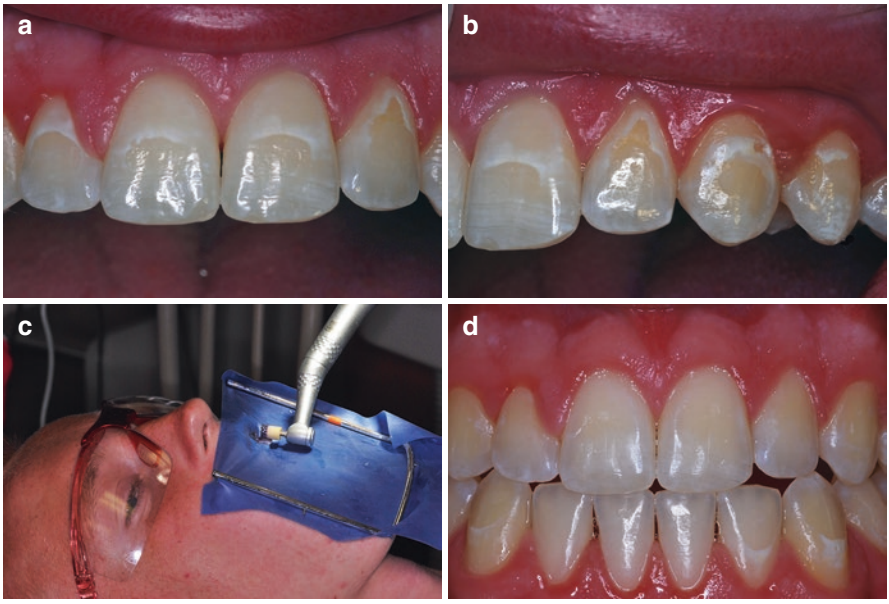

Fig. 9.3 (**a**) Decalcification from inadequate hygiene during orthodontics. (**b**) Left lateral view. Note canine Class V caries lesion and small shear fracture of first premolar. (**c**) Operative field and eye protection. PREMA® applied. (**d**) Three months after enamel microabrasion and resin-based composite restoration of the maxillary left canine tooth

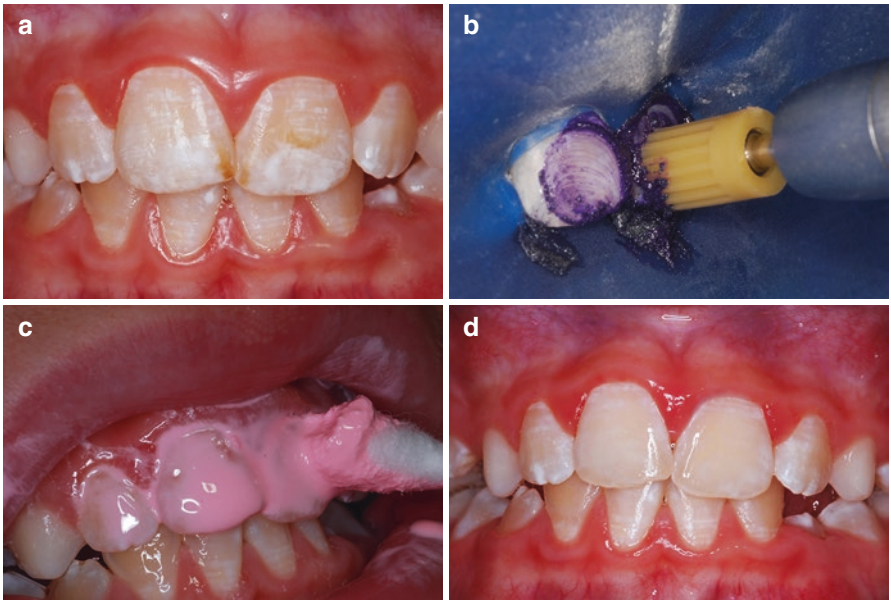

Fig. 9.4 (**a**) Ten-year-old with white and brown idiopathic enamel white and brown dysmineralization. (**b**) PREMA® applied with rubber applicator tip. (**c**) Fluoride gel applied after microabrasion completed. (**d**) Immediately after enamel microabrasion treatment

first decade. In addition, the family's water source was not fluoridated. The diagnosis was recorded as idiopathic white and brown enamel dysmineralization, possibly related to excess fluoride consumption in the early years. The parents were concerned only with the maxillary central incisors at the time of treatment. Additional enamel microabrasion for other teeth would be considered later. PREMA Compound was used to treat these teeth (Figs. 9.4a–d).

9.3.3 Case Three

An eight-year-old girl had a pitting type of amelogenesis imperfecta (Fig. 9.5a). The labial surface of her maxillary incisors had multiple round notches that did not penetrate deeply into the surface. The maxillary central incisors were affected much more than the lateral incisors. Although the appearance of these incisors could have been substantially improved with bonded resin-based composite, it was felt that the enamel defects were superficial enough to be eliminated rather than covered up (Killian and Croll 1990).

To hasten the procedure, an initial portion of the enamel removal was achieved with a slow-speed diamond bur prior to placement of the rubber dam (Fig. 9.5b). (Croll 1993) OPALUSTRE® Enamel Microabrasion Slurry was used in the same manner as PREMA Compound in the other cases shown here. Ultradent's OpalCup™

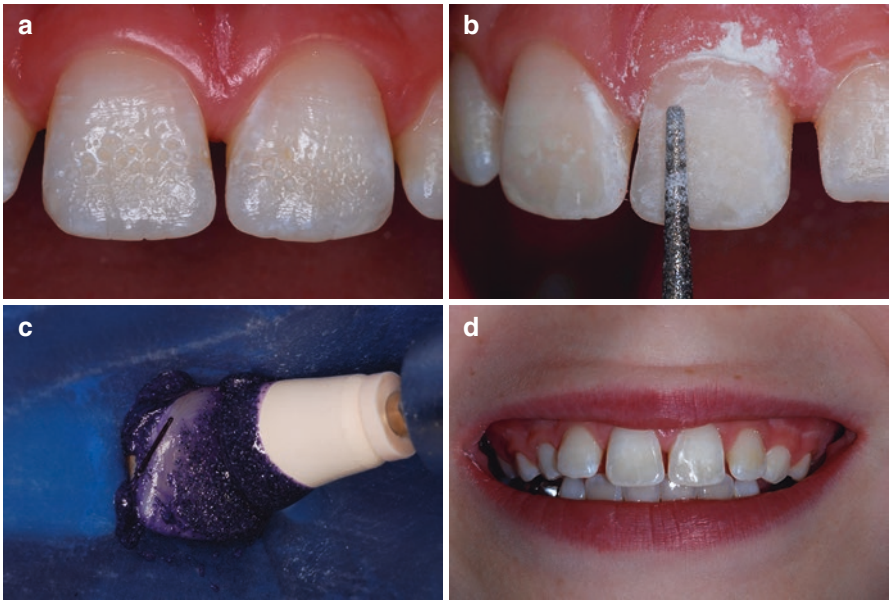

Fig. 9.5 (**a**) Eight-year-old with pitting type amelogenesis imperfecta. (**b**) Slow-speed diamond initiates enamel microreduction. (**c**) OPALUSTRE® slurry applied with rubber cup/brush assembly (OpalCup™). (**d**) Three months after enamel microabrasion, enamel texture is normal

with internal brush bristles was used to apply the slurry to all four incisors (Fig. 9.5c). Three months later, the incisors gave a much improved appearance (Fig. 9.5d).

9.3.4 Case Four

In 1985, a 10-year-old girl had white and brown idiopathic enamel dysmineralization discoloration of her maxillary central incisors. Enamel microabrasion was completed, and treatment was documented, before, immediately after, and 5 years later (Fig. 9.6a) (Croll 1991). Twenty-five years after treatment, the patient had custom-tray carbamide peroxide tooth bleaching, for additional tooth color improvement (Fig. 9.6b).

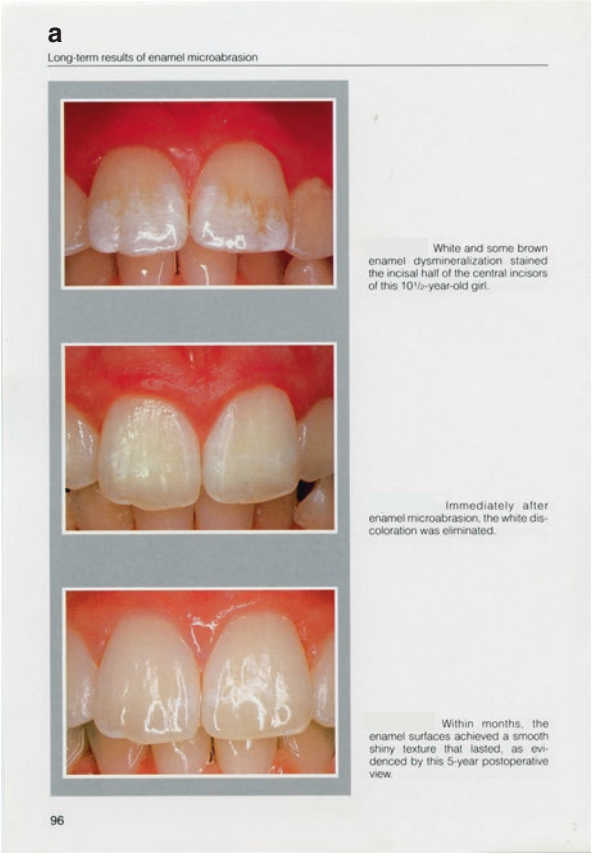

Fig. 9.6 (**a**) Enamel microabrasion of a 10-year-old in 1985, documented (Croll 1991). (**b**) Tooth appearance 27 years after enamel microabrasion and 2 years after custom-tray carbamide peroxide "home bleaching"

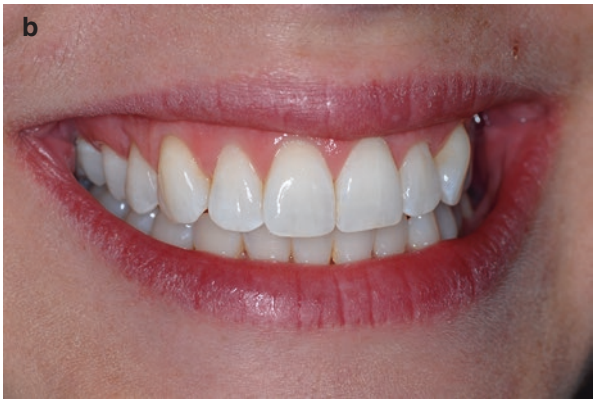

Fig. 9.6 (continued)

9.4 Discussion

After more than a quarter of a century of experience, clinical observations, and research, the following is known about enamel microabrasion:

- Enamel microabrasion is more conservative of tooth structure than treatments such as porcelain or resin-based composite veneering. It also is significantly less expensive.
- Enamel microabrasion results are permanent. The discoloration or texture abnormalities are removed, not masked with artificial material that eventually will require additional intervention.
- The glass-like surface resulting from the abrasion/erosion combination resists acid dissolution and bacteria accumulation better than untreated enamel smooth surfaces (Segura et al. 1997a, b).
- Many intrinsic enamel surface defects are superficial enough to be eliminated without the need to replace the lost enamel. Slight and moderate white and brown fluorosis discolorations are good examples of this type of dysmineralization. Teeth with deeper enamel defects are to be repaired with traditional restorative methods. In cases for which the clinician is unsure how deep the defect penetrates the surface, there is nothing to lose except clinical time, by attempting microabrasion initially.
- White enamel dysmineralization sometimes does not need to be completely removed during the microabrasion procedure. Even though residual white streaks or spots may show when the tooth is completely dry, such defects are often camouflaged when the tooth surface is saturated with body temperature saliva. Appearance of microabraded teeth should be assessed when wet with saliva, which is their usual state.

- Mechanical stripping of enamel with burs or disks can also remove superficial defects, but not in such a controlled manner and with the ensuing "enamel glaze" formation. However, time can be saved by beginning with mechanical enamel microreduction (diamond burs or disks), followed by completion of treatment with rotary application of the microabrasion compound.
- In many cases, the most striking results occur when enamel microabrasion is combined with dental bleaching. Microabrasion removes unsightly superficial defects and creates a lustrous smooth surface, while tooth bleaching whitens the deep intrinsic yellow colorations of dentin that shine through the translucent enamel surface. Microabraded teeth that also undergo dental bleaching with hydrogen peroxide products give a bright, white, and healthy appearance of long duration.

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Authors' Disclaimer The authors have no financial interest in any product or company mentioned in this chapter. The second author (TPC) formerly had financial interest in PREMA® and OPALUSTRE® by virtue of patent licensing agreements which ended with expiration of the patents.

References

Berg JH, Donly KJ (1991) The enamel surface and enamel microabrasion. In: Croll TP (ed) Enamel microabrasion. Quintessence Publishing Co., Chicago, IL, pp 55–60

Croll TP (1987) A case of enamel color modification: 60-year results. Quintessence Int 18:493–495

Croll TP (1991) Enamel Microabrasion. Quintessence Publishing Co., Chicago, p 96

Croll TP (1992) Enamel microabrasion followed by dental bleaching: case reports. Quintessence Int 23:317–321

Croll TP (1993) Hastening the enamel microabrasion procedure. J Am Dent Assoc 124:87–90

Croll TP (1998) Aesthetic correction for teeth with fluorosis and fluorosis-like enamel dysmineralization. J Esthet Dent 10:21–29

Croll TP, Bullock GA (1994) Enamel microabrasion for removal of smooth surface decalcification lesions. J Clinic Orthod 28:365–370

Croll TP, Cavanaugh RR (1986a) Enamel color modification by controlled hydrochloric acid-pumice abrasion. I Technique and examples. Quintessence Int 17:81–87

Croll TP, Cavanaugh RR (1986b) Hydrochloric acid-pumice enamel surface abrasion for color modification: results after six months. Quintessence Int 17:335–341

Cvitko E, Swift EJ, Denehy GE (1992) Improved esthetics with a combined bleaching technique: a case report. Quintessence Int 23:91–93

Donly KJ, O'Neill M, Croll TP (1992) Enamel microabrasion: a microscopic evaluation of the "Abrosion effect". Quintessence Int 23:175–179

Haywood VB, Heymann HO (1989) Nightguard vital bleaching. Quintessence Int 20:173–176

Killian CM (1993) Conservative color improvement for teeth with fluorosis-type stain. J Am Dent Assoc 124:72–74
Killian CM, Croll TP (1990) Enamel microabrasion to improve enamel surface texture. J Esthet Dent 2:125–128
McCloskey RJ (1984) A technique for removal of fluorosis stains. J Am Dent Assoc 109:63–64
Segura A, Donly KJ, Wefel JS (1997a) The effects of microabrasion on demineralization inhibition of enamel surfaces. Quintessence Int 28:463–466
Segura A, Donly KJ, Wefel JS, Drake D (1997b) Effect of enamel microabrasion on bacterial colonization. Am J Dent 10:272–274

Clinical Case of At-Home Bleaching and Enamel Microabrasion

10

Jorge Perdigão, Jennifer M. Clemente, and Carmen Real

Abstract

Enamel microabrasion has been used to remove hypomineralized areas caused by enamel fluorosis or those caused by an idiopathic cause. The combination of at-home whitening with 10% carbamide peroxide in a custom-fitted tray and enamel microabrasion is discussed and illustrated in this chapter as a successful treatment in cases of brown fluorosis stains that are not completely eliminated with at-home whitening.

10.1 Introduction

In 1986, Croll and Cavanaugh described the "enamel microabrasion" technique (Croll and Cavanaugh 1986a, b), which combines chemical erosion with mechanical abrasion (Chap. 9). The microabrasion paste, which contains hydrochloric acid (HCl) and silicon carbide, is applied by rubbing it onto the enamel surface, removing a microscopic layer of enamel (Donly et al. 1992). Patients are usually satisfied with the esthetic results upon completion of the enamel microabrasion treatment (Loguercio et al. 2007).

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In a clinical study, Divyameena et al. (2021) treated 103 teeth exhibiting fluorosis in 21 patients. Authors reported that 80% of the patients were satisfied with the treatment. No patients reported sensitivity. The drawback of the microabrasion treatment was that clinical success depended on the severity of the fluorosis.

The combination of in-office whitening with enamel microabrasion has been reported in the literature. Bertassoni et al. (2008) used in-office whitening followed by enamel microabrasion to camouflage white spot areas caused by fluorosis. The effect of the in-office whitening component of the treatment was not clear in this article, as no preoperative image was published. Celik et al. (2013a) reported that combining enamel microabrasion and in-office bleaching was more effective in the esthetic management of fluorosed teeth than enamel microabrasion without whitening. However, authors did not include a control group with in-office bleaching without microabrasion. Whitening might have lightened the fluorotic brown stains without enamel microabrasion. Sundfeld et al. (2019) reported a case of a patient that was treated with 10% carbamide peroxide in a custom-fitted tray with success 30 years after undergoing a microabrasion treatment. Franco et al. (2016) reported that the immediate or delayed combination of dental bleaching with 38% hydrogen peroxide with enamel microabrasion did not negatively influence the surface roughness or hardness of enamel. Bleaching with 35% hydrogen peroxide immediately after the enamel microabrasion procedure increases the diffusion of hydrogen peroxide through enamel by 20% (Briso et al. 2014), which makes the use on in-office whitening contraindicated as a first step in the management of enamel fluorosis cases.

Other authors have combined enamel microabrasion with at-home tray whitening. Ardu et al. (2007) treated enamel fluorosis stains using microabrasion to eliminate the superficial enamel layer, followed by at-home bleaching and direct resin-based composite restorations. These authors started with enamel microabrasion and then prescribed a home bleaching technique "to better harmonize tooth color and produce whiter teeth." Celik et al. (2013b) also advocated the use of enamel microabrasion as a first option for the management of fluorosis stains. Nonetheless, they concluded that enamel microabrasion was not very effective in removing fluorosis brown stains. The authors attributed this difficulty in removing the brown stains to the discoloration of the hypocalcified subsurface areas from external sources, probably associated with the penetration of staining agents.

There used to be two commercial enamel microabrasion materials available. PREMA (Premier Dental Products, Plymouth Meeting, PA, USA) has now been discontinued. Opalustre (Ultradent Products, South Jordan, UT, USA) is still available. Whiteness RM (FGM, Joinville, SC, Brazil) is available in other countries. These products contain a low concentration of hydrochloric acid and silicon carbide abrasive powder in a silica gel. Sundfeld et al. (2007) reported that one to ten applications of Opalustre (6.6% HCl) for 60 seconds on each tooth removed 25 μm–200 μm of enamel.

Given that at-home whitening in a custom-fitted tray is more conservative than enamel microabrasion, our recommendation is to start with the least invasive technique (bleaching). If bleaching does not result in an acceptable esthetic result, then enamel microabrasion may be indicated.

10.2 Clinical Case

The chief complaint of this 29-year-old patient was related with the brown stains of the maxillary central incisors (Fig. 10.1a, b). The medical history and the clinical exam led to the diagnosis of enamel fluorosis. After radiographic exam the treatment plan presented to the patient consisted of long-term at-home whitening with 10% carbamide peroxide with potassium nitrate and sodium fluoride (Opalescence 10% PF, Ultradent Products) in a custom-fitted tray overnight with monthly recalls. Patient was informed that whitening is not always successful in removing fluorosis-related stains and that enamel microabrasion and/or direct resin-based composite restorations might be indicated after the conclusion of the whitening treatment. Side effects of at-home whitening were also explained in detail. We also informed the patient that enamel microabrasion removes a microscopic layer of enamel.

Patient agreed with the treatment plan. After preliminary impressions and fabrication of custom-fitted soft bleaching trays, we demonstrated how to dispense the bleaching gel into the tray. Due to scheduling conflicts, the patient was only able to return after 7 weeks (Fig. 10.2a, b). The brown stains were significantly lighter at this first recall. Patient had no permanent side effects such as tooth sensitivity or soreness of the gingival tissues, but she did report mild tooth sensitivity during the first few days of the treatment. At this time, we suggested one extra month of at-home whitening following the same regimen.

The second recall took place 4 weeks later (Fig. 10.3a, b). There had been a slight improvement in the color of the maxillary incisors. At this time, in agreement

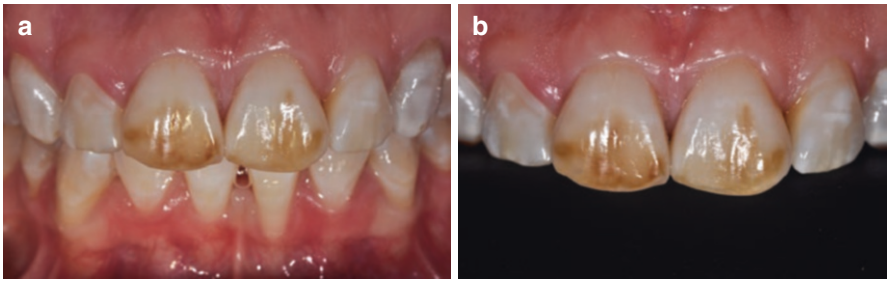

Fig. 10.1 (**a**, **b**) Preoperative view of the discolored maxillary central incisors displaying brown stains caused by fluorosis

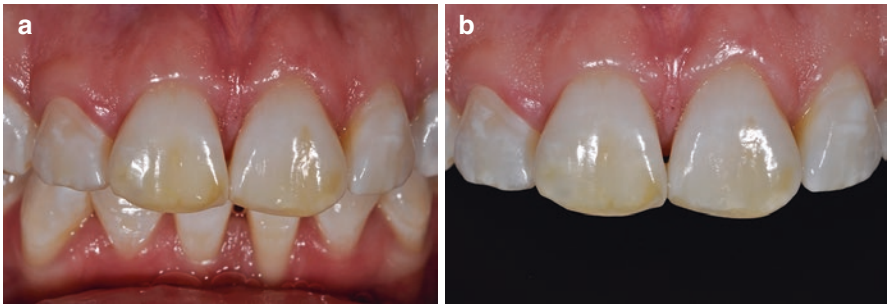

Fig. 10.2 (**a**, **b**) Clinical aspect after 7 weeks of overnight at-home whitening with 10% carbamide peroxide with potassium nitrate and sodium fluoride in a custom-fitted tray

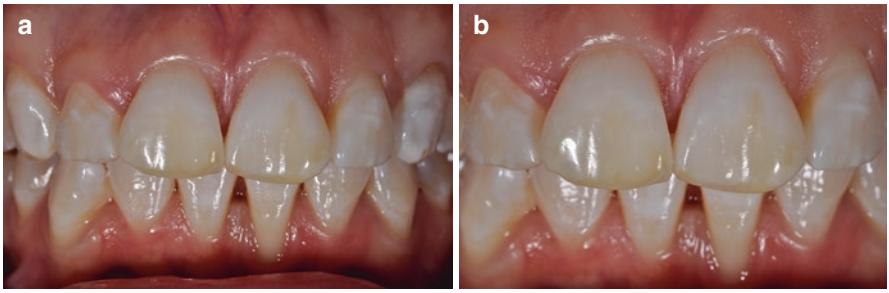

Fig. 10.3 (**a**, **b**) Patient retuned to clinic 4 weeks after the first recall

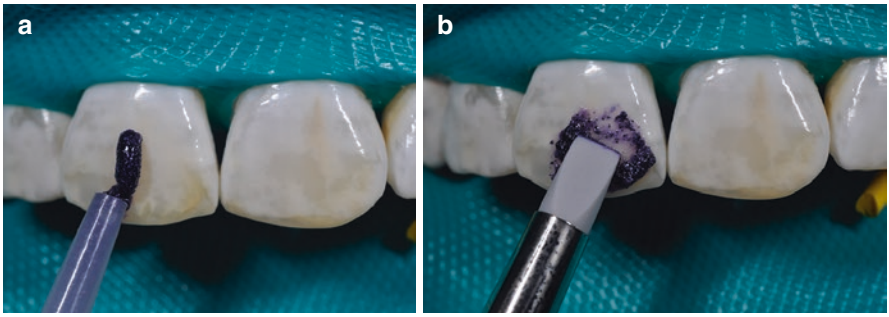

Fig. 10.4 (**a**, **b**) The four maxillary incisors were treated with an enamel microabrasion compound (Opalustre, Ultradent Products, Inc.). Six consecutive applications of 60 s each were carried out with water rinsing between each application

with the patient, we decided to perform the enamel microabrasion technique with Opalustre (Ultradent Products, Inc.) on the four maxillary incisors (Fig. 10.4a, b). Six consecutive applications of 60 seconds each were carried out, with water rinsing between each application. Figure 10.5 depicts the intense dehydration immediately after removing the rubber dam.

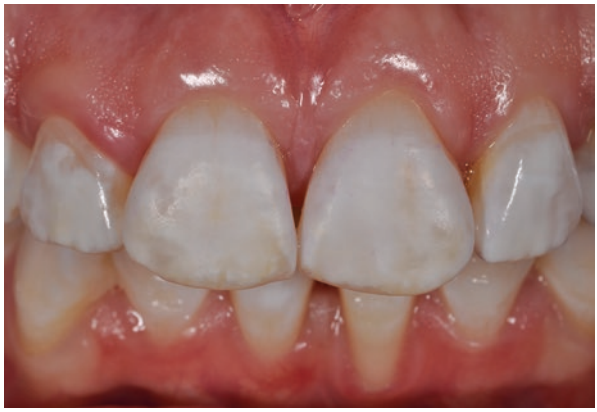

Fig. 10.5 Intense dehydration of the teeth immediately after removing the rubber dam

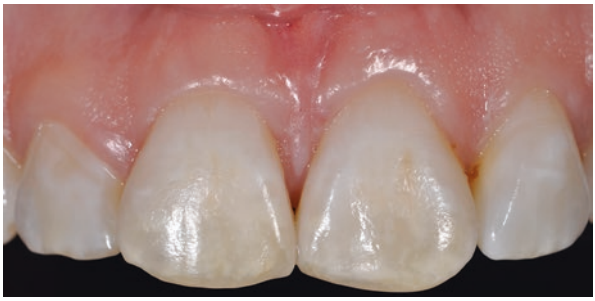

Fig. 10.6 The patient returned to clinic 2.5 months after the enamel microabrasion procedure. The patient was extremely satisfied with the color improvement of her anterior teeth. We suggested a few more weeks of at-home whitening with the same 10% carbamide peroxide gel and the same bleaching tray, following the same regimen that she had been prescribed in the beginning of the treatment

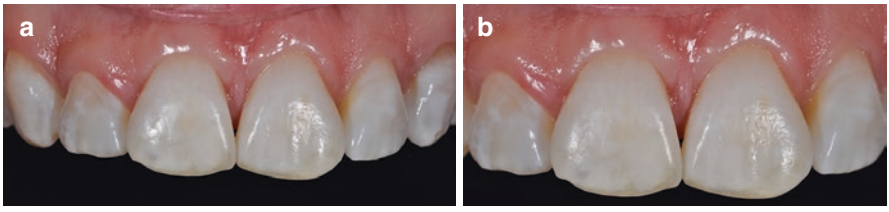

Fig. 10.7 (**a**, **b**) Clinical aspect after 3 extra weeks of at-home whitening with 10% carbamide peroxide with potassium nitrate and sodium fluoride in a custom-fitted tray. At this time the patient decided that she did not want to pursue any further treatment, as she was extremely happy with the esthetic outcome

Patient returned to the clinic 2.5 months later (Fig. 10.6). Although the patient was extremely happy with the color improvement, we suggested a few extra weeks of at-home whitening with 10% carbamide peroxide gel. Figure 10.7a, b represents the final result after 3 weeks of at-home whitening. At this time the patient decided that she did not want to pursue further treatment.

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References

Ardu S, Stavridakis M, Krejci I (2007) A minimally invasive treatment of severe dental fluorosis. Quintessence Int 38:455–458

Bertassoni LE, Martin JMH, Torno V, Vieira S, Rached RN, Mazur RF (2008) In-office dental bleaching and enamel microabrasion for fluorosis treatment. J Clin Pediatr Dent 32:185–188

Briso AL, Lima AP, Gonçalves RS, Gallinari MO, dos Santos PH (2014) Transenamel and transdentinal penetration of hydrogen peroxide applied to cracked or microabrasioned enamel. Oper Dent 39:166–173

Celik EU, Yıldız G, Yazkan B (2013a) Comparison of enamel microabrasion with a combined approach to the esthetic management of fluorosed teeth. Oper Dent 38:E134–E143

Celik EU, Yildiz G, Yazkan B (2013b) Clinical evaluation of enamel microabrasion for the aesthetic management of mild-to-severe dental fluorosis. J Esthet Restor Dent 25:422–430

Croll TP, Cavanaugh RR (1986a) Enamel color modification by controlled hydrochloric acid-pumice abrasion. I Technique and examples. Quintessence Int 17:81–87

Croll TP, Cavanaugh RR (1986b) Hydrochloric acid-pumice enamel surface abrasion for color modification: results after six months. Quintessence Int 17:335–341

Divyameena B, Sherwood A, Rathna Piriyanga S, Deepika G (2021) Clinical performance of enamel microabrasion for esthetic management of stained dental fluorosis teeth. Oper Dent 46:15–24

Donly KJ, O'Neill M, Croll TP (1992) Enamel microabrasion: a microscopic evaluation of the "abrosion effect". Quintessence Int 23:175–179

Franco LM, Machado LS, Salomão FM, Dos Santos PH, Briso AL, Sundfeld RH (2016) Surface effects after a combination of dental bleaching and enamel microabrasion: an in vitro and in situ study. Dent Mater J 35:13–20

Loguercio AD, Correia LD, Zago C, Tagliari D, Neumann E, Gomes OM, Barbieri DB, Reis A (2007) Clinical effectiveness of two microabrasion materials for the removal of enamel fluorosis stains. Oper Dent 32:531–538

Sundfeld RH, Croll TP, Briso AL, Croll TP, Briso AL, de Alexandre RS, Sundfeld Neto D (2007) Considerations about enamel microabrasion after 18 years. Am J Dent 20:67–72

Sundfeld D, Pavani CC, Schott TC, Machado LS, Pini NIP, Bertoz APM, Sundfeld RH (2019) Dental bleaching on teeth submitted to enamel microabrasion 30 years ago-a case report of patients' compliance during bleaching treatment. Clin Oral Investig 23:321–326

Resin Infiltration

11

Sebastian Paris and Hendrik Meyer-Lueckel

Abstract

Buccal white spot lesions are an unpleasant but frequent side effect of orthodontic treatment with fixed appliances, but also developmental defects such as fluorosis that appear as "white spots." Resin infiltration was originally developed to arrest the progression of non-cavitated caries lesions. The technique uses low viscosity resins that penetrate the porous lesion body of white spot lesions. After infiltration the material is light cured and thus blocks the diffusion pathways for acids and dissolved minerals. A positive side effect of resin infiltration is that infiltrated lesions lose their whitish appearance and look more similar to sound enamel. This effect can be used to camouflage esthetically impairing white spot lesions. Resin infiltration removes much less enamel compared to micro-abrasion or restorative approaches. Nonetheless, significantly better esthetic results compared with noninvasive approaches such as fluoridation can be achieved.

11.1 White Spot Lesions

White spots are among the most frequent dental esthetic impairments. While most whitish discolorations are early non-cavitated caries lesions, they may also represent developmental defects with various etiologies such as fluorosis, post-traumatic

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lesions, or molar-incisor-hypomineralization (MIH). Common for all these defects is an increased porosity of the enamel that causes the whitish and chalky appearance.

Sound enamel is relatively translucent to visible light. Due the homogeneous nature of enamel, which mostly consists of apatite crystals, light passes the enamel with only minor scattering (Fig.11.1a). In white spot lesions, of whatever origin, the enamel structure is interspersed with porosities and voids. Apatite or enamel has a refractive index of 1.62, whereas the content of the porosities has a refractive index of approximately 1.33 when the lesion is wet or 1.0 when the lesion is dry (Kidd and Fejerskov 2004). Due to the different refractive indices of the different media, light is broken at the millions of interfaces between the pores and the enamel, and thus the light is scattered (Fig. 11.1b). Because the difference in refractive index is even higher between dry pores and enamel compared to wet pores, dried lesions appear more whitish compared with wet lesions.

11.1.1 Initial Caries

Caries lesions are formed after tooth eruption by dissolution of enamel induced by cariogenic acids being produced by cariogenic bacteria during fermentation of carbohydrates. In the past caries was often regarded as a transmittable disease caused by an infection with bacteria like *Streptococcus mutans* (Keyes 1960). Today caries is rather seen as a process, triggered by the frequent intake of fermentable carbohydrates (sugars) and characterized by an ecological shift in the oral microbiology towards acidogenic and aciduric bacteria (Marsh 2003). Moreover it is emphasized that multiple (mostly protective) factors such as oral hygiene, access to fluorides, or amount and composition of saliva influence the caries process (Paris and Meyer-Lückel 2012).

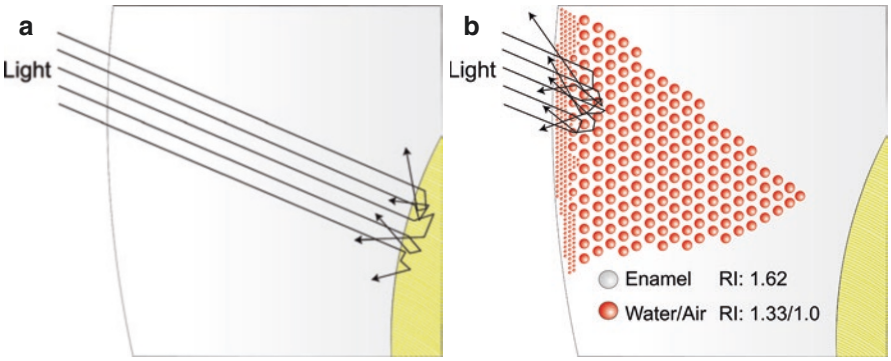

Fig. 11.1 Schematic illustration of the origin of the whitish opaque appearance of initial caries lesions and developmental defects. (**a**) Sound enamel is relatively translucent to visible light. Light beams (arrows) are primarily broken within the dentin. (**b**) In white spot lesions, pores contain media with a lower refractive index compared to enamel. Therefore, the light is scattered between the pores and the surrounding apatite crystals. Thus, the lesion appears whitish

The cariogenic bacteria produce organic acids (e.g., lactic acid), which diffuse into the tiny pores of enamel and there dissolve the enamel apatite. This causes an increasing porosity within the enamel. Thus, during the initial stages of the disease the caries lesion is characterized by porous enamel. The word "initial" may be somewhat misleading because lesions that appear as white spots are often several hundred micrometers deep, often extending up to the enamel-dentin junction or even deeper. It may take weeks to months and years until a caries lesion reaches a stage where so much mineral is lost that the lesion collapses and a cavity forms. Nevertheless, caries is a dynamic process. If the interplay of multiple etiological factors shifts towards less cariogenic conditions, lesions can take up mineral from the saliva again and start to remineralize. Usually de- and remineralization cycles alternate several times a day, but if over time remineralization overweights demineralization, the lesion does not progress but arrests. This remineralization is usually confined to the outer surface of the lesion where over time a so-called pseudo-intact surface layer is formed. This surface layer usually has a thickness of approximately 20–40 μm (but sometimes even more than 100 μm) and is considerably less porous than the underlying lesion body (Meyer-Lueckel et al. 2007). Thus, arrested or remineralized lesions look very similar to active progressing caries lesions except the higher mineralized surface. For this reason, it is a challenge to differentiate inactive lesions (enamel scars) from active progressing caries.

When white spot lesions arrest, organic components such as food pigments can be incorporated into the surface layer along with minerals. This is why some lesions may get a brownish discoloration and thus are called "brown spots" (Fig. 11.2).

Caries lesions usually develop in tooth sites where plaque formation is fostered such as in the fissure system or interproximal areas. On oral or buccal smooth surfaces, plaque formation is usually increased at the cervical margin. Quite frequently buccal caries lesions are observed after treatment with fixed orthodontic brackets. These appliances hamper the natural cleaning as well as oral hygiene and thus

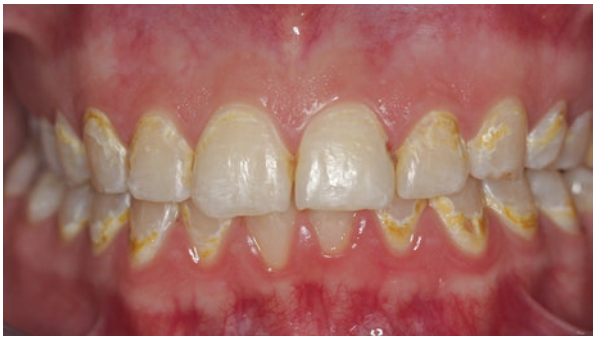

Fig. 11.2 Buccal caries lesions. A 21-year-old patient with a high caries risk several months after debonding of orthodontic brackets. Non-cavitated and partly cavitated caries lesions are located in the cervical part of the buccal surfaces. The partly yellowish-brownish discoloration is a sign of inactivation. Thus, the lesions currently do not progress further, but are considered as an esthetic impairment

promote plaque formation. After removal of the brackets, these surfaces may be easily cleaned again. This improvement in oral hygiene leads to an arrest of many buccal white spot lesions. These lesions do not need any further treatment, as they are not signs of active disease, but enamel scars. From an esthetic point of view, however, both active and inactive caries lesions are unattractive and may need intervention.

Buccal early caries lesions can be easily differentiated from developmental defects (see below) as caries only forms in plaque stagnation areas, and thus caries on buccal surfaces is confined to cervical areas or the areas around the bracket base (Lovrov et al. 2007; Mitchell 1992).

11.1.2 Developmental Defects

Developmental defects are caused by a disturbance during enamel formation. Multiple factors such as toxic agents, infections, traumas, or irradiations have been associated with this disturbance. The resulting defects can be quantitative (with a lack of enamel volume) or qualitative (with a deficiency of enamel structure) or a combination of both. Here we concentrate on qualitative defects, which are characterized by increased enamel porosity.

11.1.2.1 Fluorosis

Today, enamel fluorosis is probably the most prevalent developmental defects of human teeth. It is caused by chronic intoxication with fluorides during the phase of enamel formation. It is believed that daily fluoride doses of 40 μg/kg body weight may increase the risk of fluorosis in children, and doses above 100 μg/kg almost certainly cause dental fluorosis (Twetman and Ekstrand 2013).

Histologically enamel fluorosis is characterized by an increased porosity in the enamel (Thylstrup and Fejerskov 1978). In mild forms only the superficial enamel is affected. In severe forms nearly the complete enamel is porous, and the surface may show pits and breakdowns. Clinically mild fluorosis appears as cloudy whitish discolorations following the perikymata lines. This is the reason for their wavy appearance. In more severe forms, the white lines converge to white spots that affect from up to the complete cusp (Fig. 11.3). Very severe forms show complete opaque and chalky enamel with pitting and often brownish discolorations. Fluorosis can be distinguished from caries, since fluorosis usually affects multiple homologous teeth, which were formed during the same period. Therefore, fluorosis is often seen on homologous teeth.

11.1.2.2 Post-Traumatic Defects

Another quite prevalent class of developmental defects is caused by traumatic injuries of the primary incisors that cause a disturbance of enamel formation in the permanent successors (Diab and elBadrawy 2000). These defects can comprise

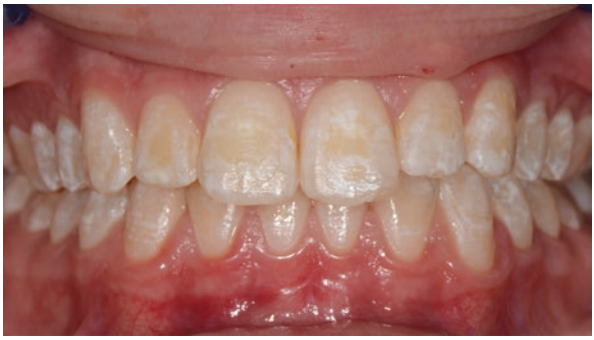

Fig. 11.3 Dental fluorosis: note the cloudy appearance

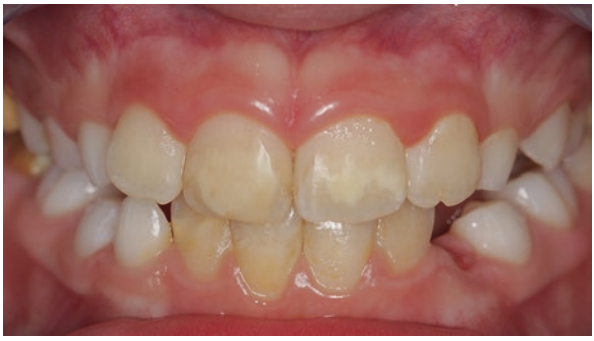

Fig. 11.4 Molar-incisor-hypomineralization (MIH). The disease is characterized by whitish opaque to yellowish (cheesy) distinct and clearly demarcated discolorations on the incisors and first permanent molars

qualitative defects (white or yellow-brown discolorations), quantitative defects (enamel hypoplasia), or combinations of both (Diab and elBadrawy 2000). Post-traumatic defects are mostly unilateral and just affect one or two teeth.

11.1.2.3 Molar Incisor Hypomineralization (MIH)

MIH is a developmental defect that affects the first permanent molars and incisors. In some cases also the second permanent molars and primary teeth show alterations. MIH lesions may appear as distinct and clearly demarcated whitish to yellowish discolorations (Willmott et al. 2008; Takahashi et al. 2009). As in other "white spots," the whitish opaque discoloration is caused by an increased porosity of the enamel (Fig. 11.4). In contrast to fluorosis, the opacity is always distinct as the porosity affects the complete enamel depth from the surface up to the enamel-dentin junction. Yellowish-brownish discolorations are caused by organic components, which fill the porosities. In severe forms the increased porosity may also lead to enamel breakdown (Weerheijm 2003).

The etiology of MIH is still unclear. It is commonly believed that the disease is multifactorial and that causing factors must be present during mineralization of the first molars and incisors, which means up to the first four years of life. As possible etiological factors, problems during pregnancy, infectious diseases, intoxication with antibiotics, and dioxins have been discussed (Takahashi et al. 2009).

11.2 Resin Infiltration

The technique of resin infiltration was originally developed to arrest non-cavitated caries lesions. The mineral loss of early caries lesions results in the formation and growth of porosities in the enamel matrix. These pores act as diffusion pathways for acids into the enamel and dissolved minerals out of the enamel. Caries infiltration aims to penetrate these pores with low-viscosity light-curing resins – so called infiltrants – that infiltrate the porous enamel driven by capillary forces (Paris et al. 2010). When the resin is light cured, it blocks the diffusion pathways and protects the remaining apatite crystals (Meyer-Lueckel and Paris 2008).

One positive side effect of resin infiltration is an immediate color change of the whitish lesion once it is infiltrated. The infiltrant resin has a refractive index of 1.52, which is close to that of enamel (1.62). Therefore, light scattering between the enamel pores and the surrounding enamel is significantly reduced when the pores are filled with resin instead of water or air (Fig. 11.5). Under best conditions the resin-infiltrated lesions are optically masked and "disappear" (Paris and Meyer-Lueckel 2009; Knösel et al. 2019).

To achieve resin infiltration of porous enamel, the lesions need to be conditioned. As the pseudo-intact surface layer has a much lower porosity compared with the underlying lesion body, it hampers penetration of the infiltrant resin and thus must be removed. This can be achieved by etching the lesion with 15% hydrochloric acid (HCl) gel for 2 min.

In the next step, the lesion must be properly desiccated. As the penetration of the infiltrant resin infiltration is based on capillary action, any other liquid within the porous enamel network would inhibit any infiltration. Usually the desiccation is achieved by a combination of air-blowing an application of ethanol and another air-blowing subsequently. Finally the infiltrant resin is applied for 3 min. Although infiltrants are chemically similar to many commercial bonding agents, it is strongly recommended not to misemploy adhesives or bonding agents for caries infiltration but to use the commercially available infiltrant kit. Infiltrant resins show a much

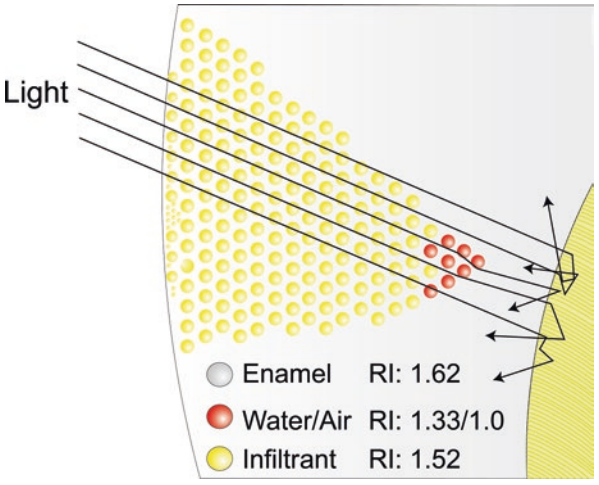

Fig. 11.5 Masking of white spot lesions by resin infiltration. As the infiltrant resin has a similar refractive index as enamel, light scattering within the white spot lesion is significantly reduced (compare with Fig. 11.1)

higher penetrability compared with bonding agents and thus ensure a deeper infiltration. But even with an infiltrant, the relatively long application time of 3 min is recommended to ensure a complete infiltration of the lesion body.

Currently there is only one commercial kit for caries infiltration on the market: Icon (DMG, Hamburg, Germany) is available for proximal or vestibular (buccal) lesions. For infiltration of esthetically relevant white spot lesions, the vestibular or anterior kit (Fig. 11.6) is recommended.

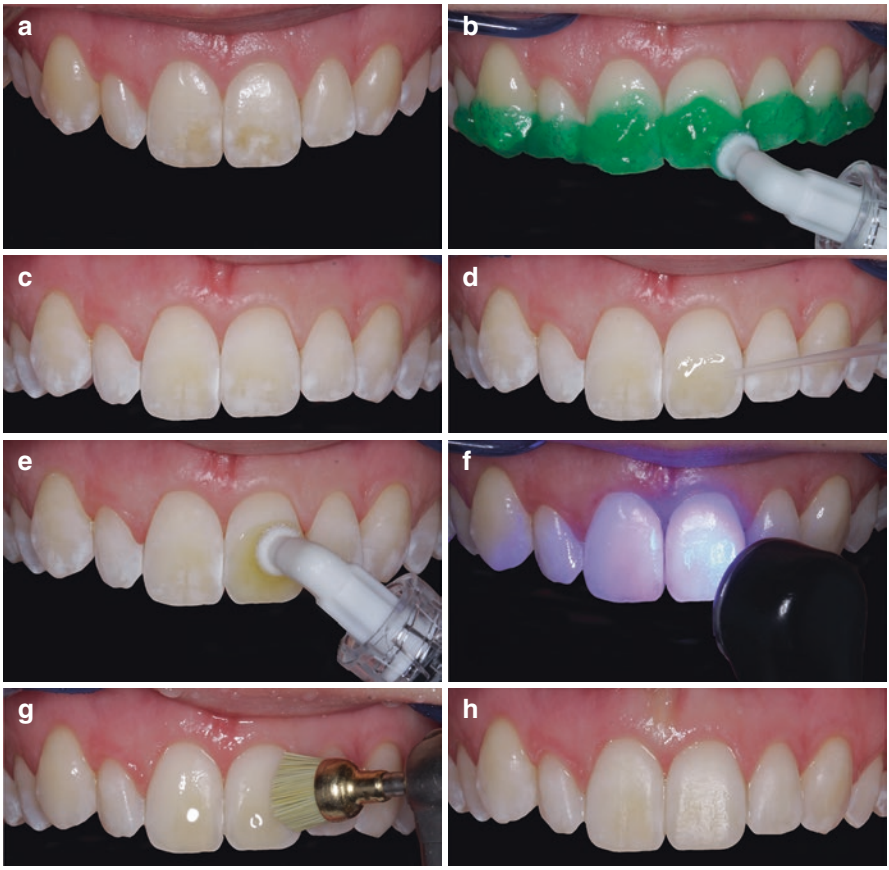

Fig. 11.6 Masking of fluorosis by resin infiltration. (**a**) Baseline. The patient complained about whitish-brownish discolorations (dental fluorosis) in the maxillary anterior teeth. (**b**) The surface layer of the lesions is eroded by etching with 15% HCl for 2 min. As the fluorotic lesions are located only on the incisal two thirds of the crowns, no rubber dam isolation was necessary. (**c**) After rinsing the etchant and drying, the teeth look frosty due to the etching pattern. Notice that the lesions are still visible as only the surface layer was eroded. (**d**) Ethanol is applied to check for the completeness of surface layer erosion (please see text for explanation). The ethanol is subsequently evaporated to desiccate the lesion as much as possible. (**e**) During the application of the infiltrant resin, an immediate color change can be observed. (**f**) After 3 min, resin surplus is removed, and the material is light cured. A second infiltration step compensates for the polymerization shrinkage. (**g**) Resin-infiltrated lesions are polished to remove the etching pattern and the oxygen-inhibited outermost resin layer. (**h**) The immediate result shows complete camouflage of the lesions

11.3 Case Selection

11.3.1 Infiltration of Buccal Caries

Many patients in need for an esthetic rehabilitation of buccal white spots had a treatment with fixed orthodontic appliances. It should be ensured that the pathogenic factors causing the caries are under control, before esthetic rehabilitation is planned. Although successful caries infiltration will also arrest lesions, patients should be able to maintain proper oral hygiene. To improve the esthetics of the teeth with white spot lesions, several treatment options should be considered:

- Enhancing remineralization
- Bleaching
- Resin infiltration
- Micro-abrasion
- Composite restorations
- Veneers

In this list of treatment options, the invasiveness increases from remineralization methods towards the esthetic rehabilitation using veneers. At the same time the predictability of the esthetic outcome improves. Thus the choice of treatment is influenced by the predictable esthetic outcome of a technique being expected by an individual patient as well as the loss of enamel that has to be removed in order to achieve the respective esthetic result. In this context it should be considered that especially for young patients, in doubt, the less invasive methods should always be preferred, and restorations should be postponed as long as possible (Qvist 2008).

Caries infiltration is "located" in the middle of the various treatment options and thus may be an interesting microinvasive approach to achieve good esthetic results with a minimum loss of enamel. To predict the esthetic outcome of caries infiltration, two factors should be considered:

Lesion depth: The deeper the lesions are, the harder it is to achieve a complete camouflage by resin infiltration. Thus, the more whitish a lesion appears even before drying, the harder it is to reach a complete masking.

Lesion activity: Active lesions are easier to infiltrate compared with inactive lesions. As mentioned above the pseudo-intact surface layer inhibits the penetration of the underlying lesion body, and active caries lesions usually exhibit shallower and lower mineralized surface layers compared with inactive lesions. Therefore, for active lesions less surface erosion is required, and often better esthetic results are observed in most cases. For this reason it might be considered to treat buccal lesions shortly after the removal of orthodontic brackets.

11.3.2 Infiltration of Developmental Defects

Due to their histological similarity to caries lesions, also developmental hypomineralized defects can be resin infiltrated. It could be shown that good esthetic results can be expected for cases of mild to moderate fluorosis (Auschill et al. 2015; Attal et al. 2014; Gugnani et al. 2014). Similarly, mild post-traumatic lesions (Munoz et al. 2013) may also be camouflaged by resin infiltration. For MIH lesions, however, both in vitro results (Crombie et al. 2014) and clinical reports (Kim et al. 2011) showed rather unreliable esthetic results. It seems that yellowish or brownish discolored MIH lesions show inferior esthetic outcomes compared with whitish lesions. This might explain why MIH lesions are obviously harder to be infiltrated as these discolorations are associated with a high content of organic material. Thus, in these lesions infiltration is possibly hampered by the organic material that fills the enamel pores and thus blocks resin penetration. Nonetheless, an infiltration of the underlying lesion and a "superficial" composite restoration of ca. 100–200 µm in depth might be a very minimal invasive technique to be used in MIH teeth where infiltration alone did not work.

Box 11.1
Esthetic Indications for Caries Infiltration

- Active non-cavitated vestibular caries lesions.
- Mild fluorosis (TSIF 1–3).
- Mild developmental defects caused by trauma or infection.

Limitations of caries infiltration

- Inactive lesions
- Longer etching or micro-abrasion might be required.
- Enamel breakdown
- A combination of infiltration and subsequent restoration with composite resin is possible.
- MIH lesions
- Studies showed that MIH lesions are in esthetically insufficiently camouflaged in 50% of the cases due to partial infiltration.

Contraindications for caries infiltration

- Dentin caries or cavities into dentin.
- The infiltrating resin is too hydrophobic to infiltrate the relatively wet dentin.

11.4 Treatment

Before treatment the teeth should be cleaned using prophylaxis paste. To isolate the gingiva and protect it from the applied chemicals, rubber dam is strongly recommended. Ligatures are usually necessary for conventionl rubber dam; however, light-curing resin-based dam, also known as gingival resin barrier, has been shown to be easier to apply and more convenient for the patient. During the application of light-cured resin-based dam, it should be ensured that the plastic dam seals the gingiva tightly without covering cervical lesions. For lesions that are located very close to the cervical gingival margin, retraction cords may help to displace the gingiva before the application of the light-cured resin-based dam.

In the next step, the surface layer is eroded by the application of 15% hydrochloric acid gel (Icon etch) for 2 min. In most cases it is advisable to cover all buccal aspects with the etching gel to achieve a homogeneous appearance. Separation of the proximal contact points is usually not necessary. Before rinsing the etching gel, it is advisable to remove the bulk of the gel with a high-speed suction tip in order to avoid flushing the strong acid into the oral cavity.

The etching step not only removes the outer 30–40 μm of the surface layer but also most brownish discolorations of caries lesions as these discolorations are often located in the outer lesion surface. Thus, after etching most lesions show a chalky, brightly whitish appearance. In the next step, the lesion needs to be properly desiccated. This is achieved by air-blowing followed by application of ethanol (Icon dry), which is also evaporated by air-blowing subsequently.

This step should also be used to check if sufficient erosion of the surface layer has occurred. Buccal lesions, especially those that are inactive, may have thick and highly mineralized surface layers. In this case 2 min etching with 15% HCl may not be sufficient to erode the complete surface layer, and infiltration of the lesion body might be impaired.

During the penetration of the ethanol into the air-dried lesion, a similar color change similar to that that occurs after the subsequent resin infiltration step should be observed within the first 3–4 s after application. The color change from whitish chalky to nearly enamel colored during this “re-wetting test” is usually not as distinct as during the application of the resin but gives a good estimate of the later esthetic outcome. If this color change during the application of ethanol on the dried lesion fails to appear and the lesion remains whitish, it is quite likely that the surface layer is not completely eroded yet. In this case a second application of the etching gel for another 2 min is recommended. In some cases – especially in “older” inactive lesions – even a third application or micro-abrasion of 100–150 μm is necessary. For that purpose the 15% HCl etching gel can be mixed with some pumice and then rubbed on the lesion surface using rubber cup polishers. Care should be taken not to abrade too much enamel. In contrast to classical micro-abrasion, only the surface layer needs to be removed rather than the complete lesion.

To check for the completeness of erosion after each etching step, the “re-wetting test” should be repeated. If the result is positive, the lesion can be finally desiccated. The drying of the lesion is an absolutely essential step as resin infiltration is based

on capillary forces, which only work when the pores within the lesion body are filled with air but not water.

The infiltrant (Icon infiltrant) is applied after drying. Again an immediate color change is usually observed. The resin is now allowed to infiltrate the lesion body for approximately 3 min. In deep lesions longer application times may be necessary. The camouflage effect can be directly observed, so that longer application times may be used if necessary. During the entire application time, the light should be dimmed to avoid premature polymerization.

All excess resin is removed from the lesion surface prior to light curing using foam pellets or cotton rolls so that only the resin inside the lesion remains and hardens with light curing. Due to the polymerization shrinkage, the resin must be applied a second time for 1 min, the excess removed, and the material light cured.

To polish the surface still rough from the etching step and to remove the oxygen-inhibited resin layer, the resin-infiltrated lesions need to be polished. This step is quite important as the thin oxygen-inhibited resin layer may attract food stains if no polishing is performed, which may lead to swift discoloration of the treated surfaces.

The whole procedure for one arch usually takes about 20–30 min. The immediate masking of the lesions is quite satisfactory for the patient in most cases. As during treatment the teeth are desiccated, the final esthetic result improves after a few days compared to immediately after treatment.

Box 11.2: Treatment Procedure for Caries Infiltration to Camouflage White Spot Lesions

1. Cleaning of teeth.
2. Isolation with rubber dam or light-cured resin dam.
3. Etching with 15% HCl for 2 min.
4. Rinsing and drying.
5. Re-wetting with ethanol to check completeness of surface layer erosion: if negative repeat steps 3–5; if positive move on with step 6.
6. Desiccation of ethanol.
7. Application of infiltrant for approx. 3 min (or longer if necessary).
8. Removing of resin surplus.
9. Light curing.
10. Polishing.

11.5 Conclusion and Outlook

Although a complete masking cannot be achieved with resin infiltration in every case, a significant improvement of esthetics is usually observed in the majority of lesions. While shallower caries lesions can often be completely masked, deep caries lesions may at least show some color improvement. Currently only few long-term studies available focused on the color stability of resin-infiltrated lesions. However,

it seems that infiltrated lesions show similar staining as sound enamel (Knösel et al. 2019; Paris et al. 2013). Fluorotic white spots and those caused by traumatic injury can be masked quite well. For MIH lesions esthetic results might not be as good.

In conclusion, resin infiltration is a microinvasive approach that adds to the existing "tool box" of treatment options to improve the esthetics of buccal white spot lesions. Due to its relatively easy application, low cost, and satisfying results, it may be considered as the first-line treatment option in many cases of vestibular white spot lesions.

References

Attal JP, Atlan A, Denis M, Vennat E, Tirlet G (2014) White spots on enamel: treatment protocol by superficial or deep infiltration (part 2). Int Orthod 12:1–31. https://doi.org/10.1016/j.ortho.2013.12.011

Auschill TM, Schmidt KE, Arweiler NB (2015) Resin infiltration for aesthetic improvement of mild to moderate fluorosis: a six-month follow-up case report. Oral Health Prev Dent 13:317–322. https://doi.org/10.3290/j.ohpd.a32785

Crombie F, Manton D, Palamara J, Reynolds E (2014) Resin infiltration of developmentally hypomineralised enamel. Int J Paediatr Dent 24:51–55. https://doi.org/10.1111/ipd.12025

Diab M, elBadrawy HE (2000) Intrusion injuries of primary incisors. Part III: effects on the permanent successors. Quintessence Int 31:377–384

Gugnani N, Pandit IK, Goyal V, Gugnani S, Sharma J, Dogra S (2014) Esthetic improvement of white spot lesions and non-pitted fluorosis using resin infiltration technique: series of four clinical cases. J Indian Soc Pedod Prev Dent 32:176–180. https://doi.org/10.4103/0970-4388.130996

Keyes PH (1960) The infectious and transmissible nature of experimental dental caries. Findings and implications. Arch Oral Biol 1:304–320

Kidd EAM, Fejerskov O (2004) What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. J Dent Res 83 Spec No C:C35–C38

Kim S, Kim EY, Jeong TS, Kim JW (2011) The evaluation of resin infiltration for masking labial enamel white spot lesions. Int J Paediatr Dent 21:241–248. https://doi.org/10.1111/j.1365-263X.2011.01126.x

Knösel M, Eckstein A, Helms HJ (2019) Long-term follow-up of camouflage effects following resin infiltration of post orthodontic white-spot lesions in vivo. Angle Orthod 89:33–39

Lovrov S, Hertrich K, Hirschfelder U (2007) Enamel demineralization during fixed orthodontic treatment - incidence and correlation to various Oral-hygiene parameters. J Orofac Orthop 68(5):353–363

Marsh PD (2003) Are dental diseases examples of ecological catastrophes? Microbiology 149(Pt 2):279–294

Meyer-Lueckel H, Paris S (2008) Progression of artificial enamel caries lesions after infiltration with experimental light curing resins. Caries Res 42:117–124. https://doi.org/10.1159/000118631

Meyer-Lueckel H, Paris S, Kielbassa AM (2007) Surface layer erosion of natural caries lesions with phosphoric and hydrochloric acid gels in preparation for resin infiltration. Caries Res 41:223–230. https://doi.org/10.1159/000099323

Mitchell L (1992) Decalcification during orthodontic treatment with fixed appliances—an overview. Br J Orthod 19:199–205

Munoz MA, Arana-Gordillo LA, Gomes GM, Gomes OM, Bombarda NH, Reis A, Loguercio AD (2013) Alternative esthetic management of fluorosis and hypoplasia stains: blending effect obtained with resin infiltration techniques. J Esthet Restor Dent 25:32–39. https://doi.org/10.1111/j.1708-8240.2012.00527.x

Paris S, Meyer-Lückel H (2012) Paradigmenwechsel. In: Meyer-Lückel H, Paris S, Ekstrand KR (eds) Karies, Wissenschaft und klinische Praxis. Thieme, Stuttgart, pp 70–75

Paris S, Meyer-Lueckel H (2009) Masking of labial enamel white spot lesions by resin infiltration-a clinical report. Quintessence Int 40:713–718

Paris S, Hopfenmuller W, Meyer-Lueckel H (2010) Resin infiltration of caries lesions: an efficacy randomized trial. J Dent Res 89:823–826. https://doi.org/10.1177/0022034510369289

Paris S, Schwendicke F, Keltsch J, Dorfer C, Meyer-Lueckel H (2013) Masking of white spot lesions by resin infiltration in vitro. J Dent 41(Suppl 5):e28–e34. https://doi.org/10.1016/j.jdent.2013.04.003

Qvist V (2008) Longevity of restorations: the 'death spiral'. In: Fejerskov O, Kidd EAM (eds) Dental caries: the disease and its clinical management, vol 2. Blackwell Munksgaard, Oxford, pp 444–455

Takahashi K, Correia Ade S, Cunha RF (2009) Molar incisor hypomineralization. J Clin Pediatr Dent 33:193–197

Thylstrup A, Fejerskov O (1978) Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes. Community Dent Oral Epidemiol 6:315–328

Twetman S, Ekstrand KR (2013) Caries management by influencing mineralization. In: Meyer-Lueckel H, Paris S, Ekstrand KR (eds) Caries management - science and clinical practice, vol 1. Thieme, Stuttgart, pp 176–192

Weerheijm KL (2003) Molar incisor hypomineralisation (MIH). Eur J Paediatr Dent 4:114–120

Willmott NS, Bryan RA, Duggal MS (2008) Molar-incisor-hypomineralisation: a literature review. Eur Arch Paediatr Dent 9:172–179. https://doi.org/10.1007/BF03262633

Clinical Case of At-Home Bleaching and Resin Infiltration

12

George Gomes, Filipa Oliveira, and Jorge Perdigão

Abstract

Minimally invasive concepts in Restorative Dentistry involve noninvasive and microinvasive strategies. Noninvasive procedures aim at arresting or reverting noncavitated enamel caries lesions, while microinvasive procedures involve barriers that prevent further dissolution of enamel by the acidic challenge of cariogenic bacteria. Enamel white spot lesions (EWSL) correspond to the pre-cavitation phase of the caries process, in which enamel hydroxyapatite has been lost from the enamel subsurface leaving an apparently intact or pseudo-intact surface layer covering the mineral-deprived area. EWSL have become an esthetic challenge when they occur in anterior teeth. The microinvasive treatment of choice for EWSL is resin infiltration. The infiltration of the demineralized enamel using a low-viscosity light-cured resin with a refractive index similar to that of hydroxyapatite has been shown to reverse the opacity of the EWSL resulting in a very esthetic outcome. At-home bleaching can be prescribed for darker teeth prior to the resin infiltration.

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12.1 Introduction

In 1908 Dr. Greene Vardiman Black (Black 1908) described with great detail in page 34 "White Spots in the Enamel" as "white enamel seen in occasional white or ashy gray spots occurring in the enamel of teeth otherwise normal in color and form. These white spots are usually small and are covered with the ordinary glazed surface of the enamel, so that an exploring tine will glide over them the same as over the perfect enamel." Dr. Black's description of enamel white spot lesions is still up to date after 115 years.

The work of Applebaum (1932) with polarized microscopy, later confirmed by Silverstone, reported that the surface of early enamel lesions remained relatively unchanged, displaying an apparently intact outer layer. Enamel white spot lesions (EWSL) are incipient caries lesions in which hydroxyapatite has been dissolved from the enamel subsurface creating a demineralized enamel area covered with a relatively intact surface layer.

The concept of resin infiltration after enamel etching with hydrochloric acid (HCl) was introduced by Robinson et al. (1976) as a potential cariostatic treatment. Croll (1987) used a clear resin sealant on phosphoric acid-etched enamel to saturate the surfaces with resin for smooth surface enamel defects. The research group of Paris and Meyer-Lueckel (2009) described the masking of EWSL with resin infiltration using 15% HCl etching followed by a drying step with ethanol and a very-low-viscosity light-cured resin with tetraethylene glycol dimethacrylate (TEGDMA). Under the scanning electron microscope, the enamel demineralized area is completely filled with a low-viscosity resin to replace the dissolved hydroxyapatite, creating an enamel hybridized area while masking the enamel opacity (Perdigão 2020). More recently, an in vitro study (Meyer-Lueckel et al. 2022) reported that rubbing an abrasive-rich HCl gel onto the enamel surface with a brush is more effective than the HCl gel used currently in eroding the intact surface layer and enabling the subsequent resin infiltration.

Clinical studies have reported the effectiveness of resin infiltration in preventing the progression of class II caries lesions in primary and permanent teeth (Bagher et al. 2018; Faghihian et al. 2019; Paris et al. 2020). For the anterior teeth, the resin-infiltrated post-orthodontic white spot lesions seem to assimilate the color of adjacent enamel with stable results up to 4 years (Cazzolla et al. 2018; Knösel et al. 2019).

Not all white or brown spots are caused by fluorosis. Some of these stains may be considered idiopathic (Cutress and Suckling 1990; Gomes et al. 2006). Enamel "dysmineralization" has been used to refer to fluorosis-like discolorations (Croll 1990).

12.2 Clinical Technique

A 28-year-old patient sought dental care to inquire about the possibility of masking the "white areas" in the maxillary anterior teeth. Additionally, the patient was not happy with the overall "yellow" color of the teeth. The patient's medical history did not shed any light into the cause of the white spots. Patient recollection was that these whitish areas were visible since the early teenage years.

The clinical exam revealed that the periodontal condition was excellent with no probing depths >3 mm. There were a few areas of recession without root sensitivity. Periapical radiographs of the anterior teeth did not disclose any pathology.

The treatment plan presented to the patient included at-home whitening with 10% carbamide peroxide gel (with potassium nitrate and sodium fluoride) in a custom-fitted tray overnight for 3 weeks, followed by enamel etching of the white spot areas with 15% hydrochloric acid (HCl) and resin infiltration.

The step-by-step treatment is described in Figs. 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 12.10, 12.11, 12.12, 12.13, 12.14, 12.15, 12.16, 12.17, 12.18, 12.19, 12.20, 12.21, and 12.22. The patient was very satisfied with the esthetic outcome.

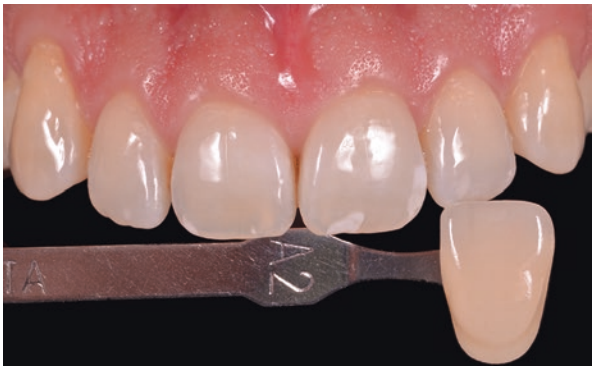

Fig. 12.1 Preoperative view of the patient's maxillary anterior teeth. An A2 Vita Classical A1–D4 shade tab (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) is shown as reference

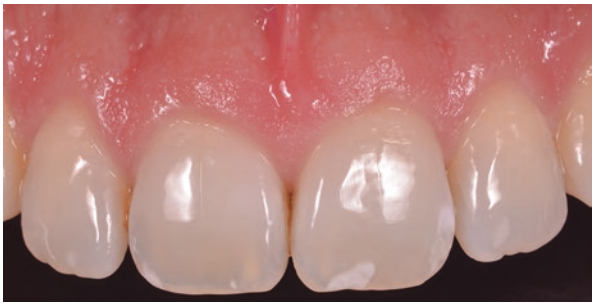

Fig. 12.2 Higher-magnification view of the maxillary incisors with EWSL. Tooth #9 (FDI 2.1) had the widest white spot areas

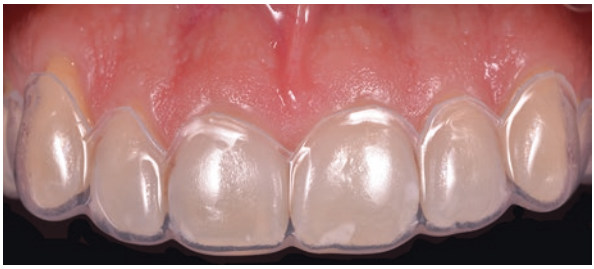

Fig. 12.3 Scalloped custom-fitted bleaching tray short of the gingival tissues to prevent tissue irritation

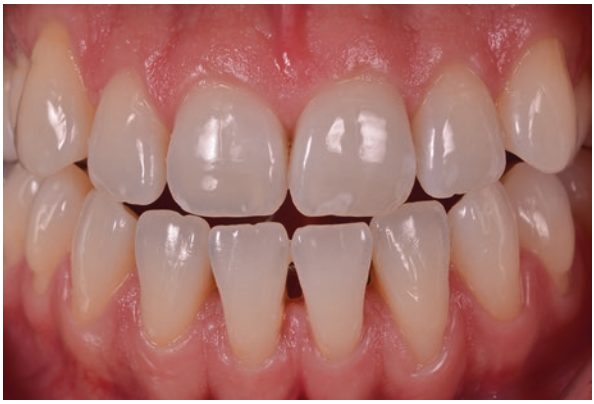

Fig. 12.4 Aspect of the anterior teeth after 9 days of overnight at-home whitening with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Whiteness Perfect 10%, FGM, Joinville, SC, Brazil) in a custom-fitted tray

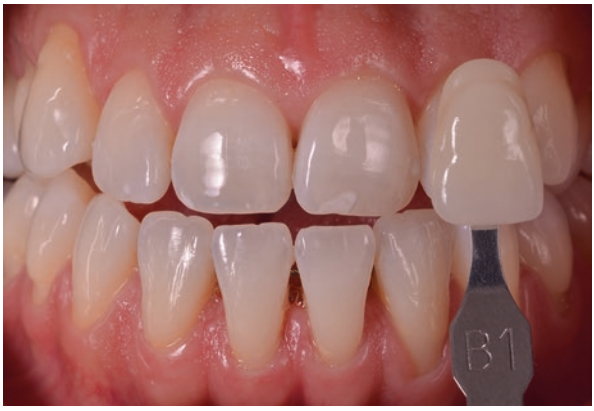

Fig. 12.5 Aspect of the anterior teeth after 21 days of at-home whitening. Patient was extremely happy with the lighter color of the teeth

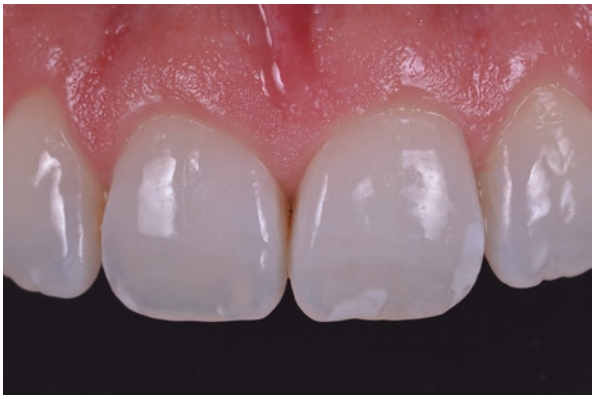

Fig. 12.6 Patient was scheduled for a resin infiltration procedure 2 weeks after finishing the at-home whitening treatment

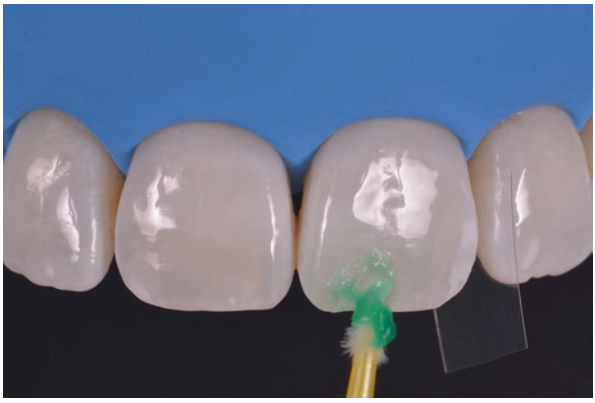

Fig. 12.7 The teeth were cleaned with a suspension of pumice and water and thoroughly washed with water. Area was isolated with a rubber dam. A 15% HCl gel (Icon-Etch, DMG, Hamburg, Germany) was applied to the white spot areas of tooth #9 (FDI 2.1). The respective manufacturer provides an application tip in the respective kit; however, we prefer a small round brush to ensure application accuracy

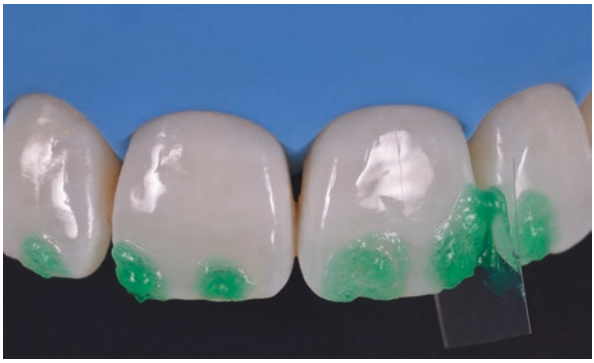

Fig. 12.8 The 15% HCl gel was extended to the other white spot areas and left undisturbed for 2 minutes

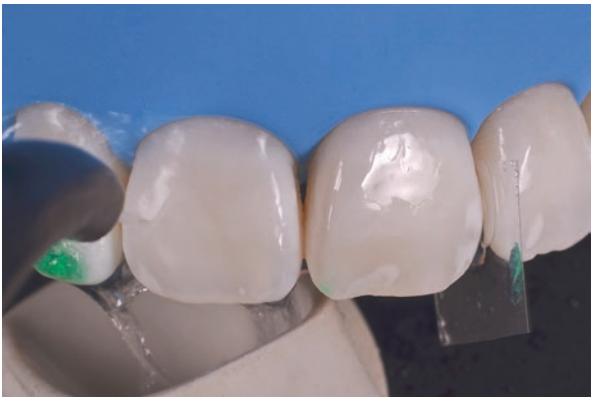

Fig. 12.9 The gel was thoroughly rinsed with water for 30 seconds with the high-speed suction tip positioned as close as possible to the area being washed. The EWSL on tooth #9 (FDI 2.1) were etched for a second time with 15% HCl gel for 2 minutes, as recommended by the respective manufacturer

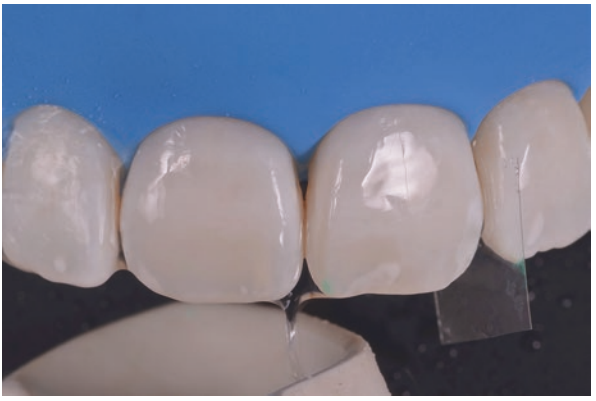

Fig. 12.10 The teeth were thoroughly rinsed with water and inspected to make sure that all residual gel had been removed

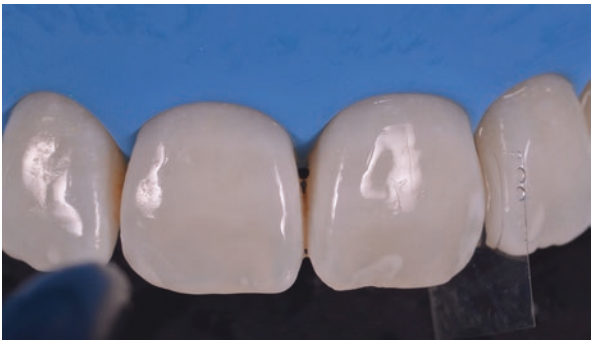

Fig. 12.11 The teeth were air-dried with water- and oil-free air for 15 seconds

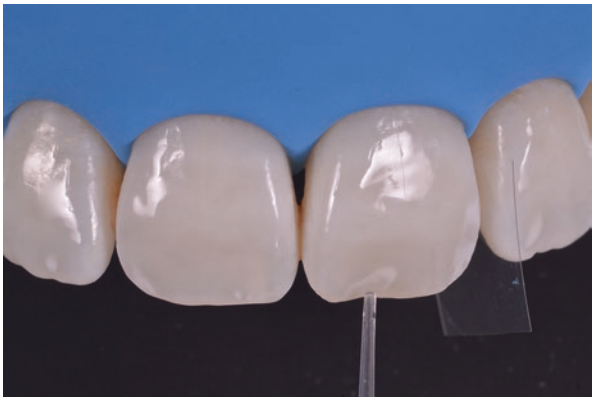

Fig. 12.12 A generous amount of Icon-Dry (DMG), which is composed of ethanol, was applied to the white spot areas and left undisturbed for 30 seconds. The teeth were air-dried with water- and oil-free air for 15 seconds

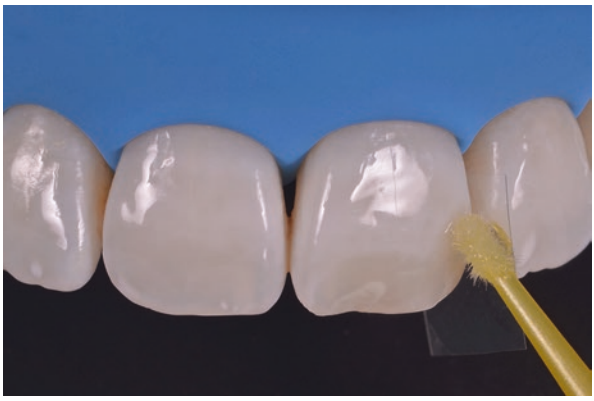

Fig. 12.13 An abundant amount of Icon-Infiltrant (DMG), which contains TEGDMA, initiators, and stabilizers, was applied to the areas that had been etched with 15% HCl and left undisturbed for 3 minutes

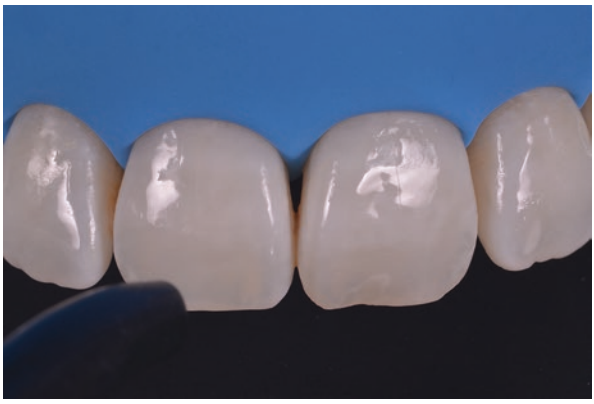

Fig. 12.14 Excess material was gently air-blown for 5 seconds to prevent pooling around the incisal edge

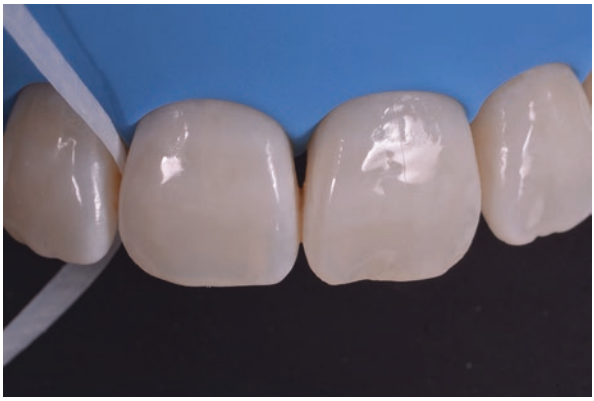

Fig. 12.15 Excess resin was removed with cotton pellets and dental floss

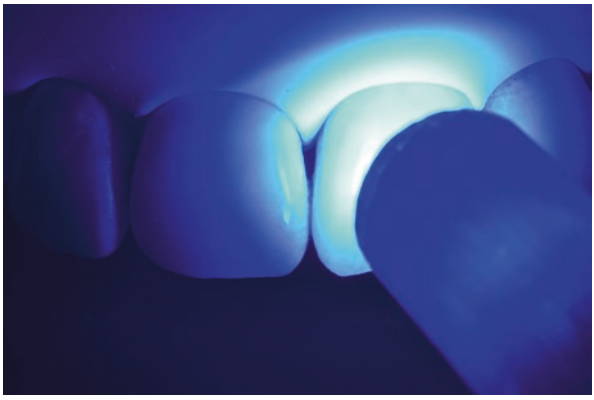

Fig. 12.16 The resin was light-cured for 40 seconds in each tooth

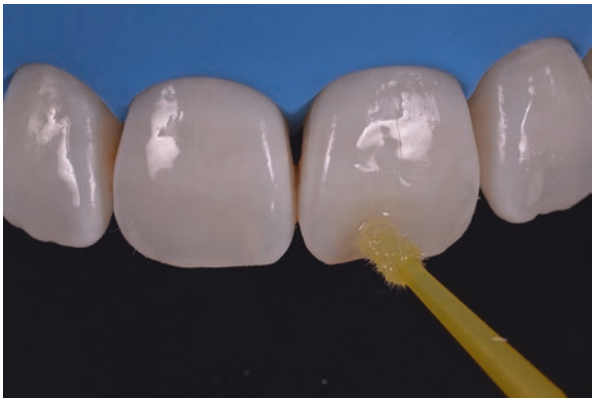

Fig. 12.17 Icon-Infiltrant (DMG) was reapplied and left undisturbed for 1 minute. Excess was removed as described above, followed by light curing for 40 seconds in each tooth

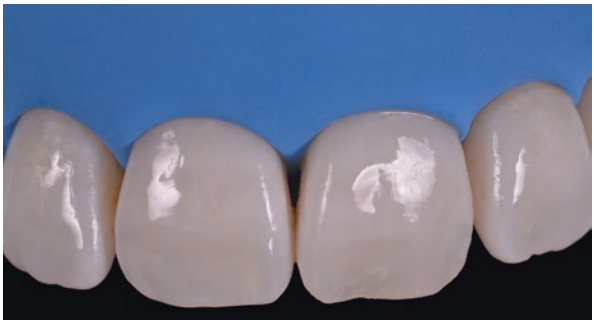

Fig. 12.18 Aspect of the anterior teeth immediately after light curing

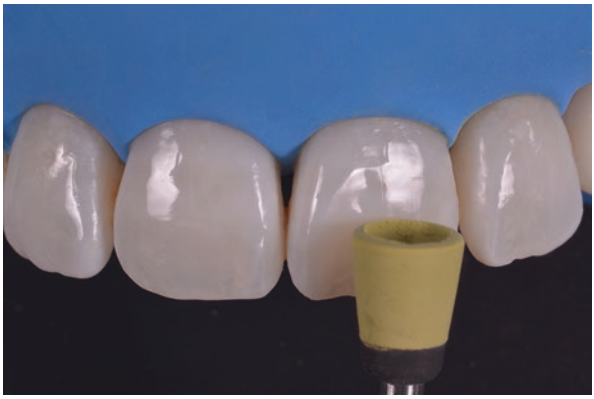

Fig. 12.19 The treated areas were polished with rubber points in slow speed

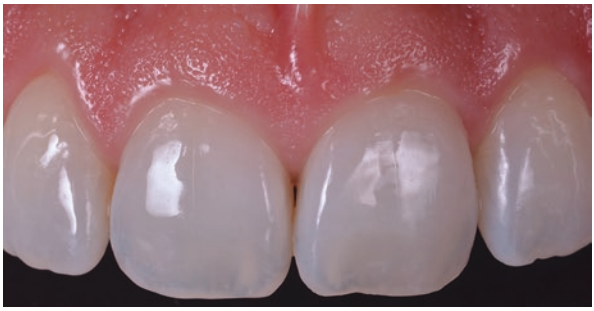

Fig. 12.20 Aspect of the treated teeth immediately after removing the rubber dam

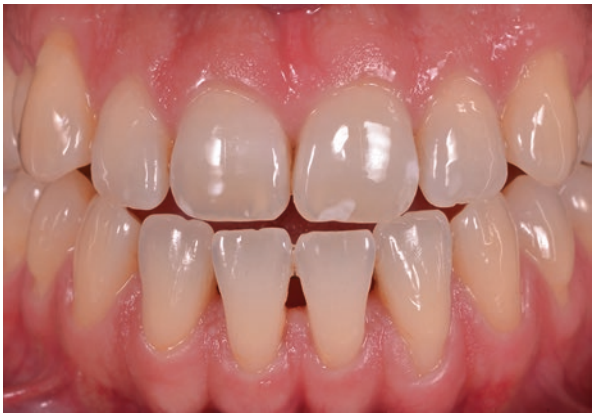

Fig. 12.21 Preoperative view

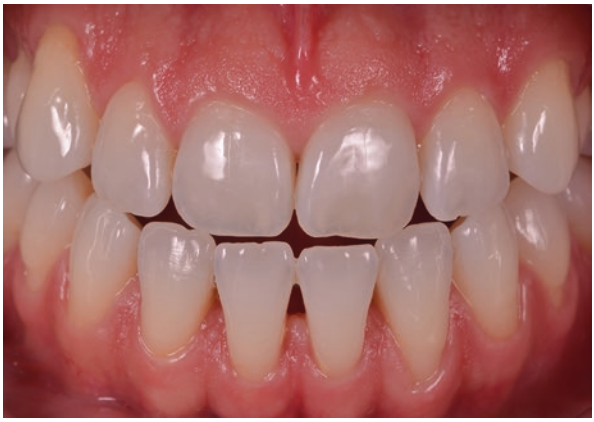

Fig. 12.22 Postoperative view

References

Applebaum E (1932) Incipient dental caries. J Dent Res 1932:619–627
Bagher SM, Hegazi FM, Finkelman M, Ramesh A, Gowharji N, Swee G, Felemban O, Loo CY (2018) Radiographic effectiveness of resin infiltration in arresting incipient proximal enamel lesions in primary molars. Pediatr Dent 40:195–200
Black GV (1908) A work on operative dentistry in two volumes. Medico-Dental Publishing Company, Chicago, IL
Cazzolla AP, De Franco AR, Lacaita M, Lacarbonara V (2018) Efficacy of 4-year treatment of icon infiltration resin on postorthodontic white spot lesions. BMJ Case Rep 2018:bcr2018225639
Croll TP (1987) Bonded resin sealant for smooth surface enamel defects: new concepts in "micro-restorative" dentistry. Quintessence Int 18:5–10
Croll TP (1990) Enamel microabrasion for removal of superficial dysmineralization and decalcification defects. J Am Dent Assoc 120:411–415
Cutress TW, Suckling GW (1990) Differential diagnosis of dental fluorosis. J Dent Res 69 Spec No:714–720. discussion 721
Faghihian R, Shirani M, Tarrahi MJ, Zakizade M (2019) Efficacy of the resin infiltration technique in preventing initial caries progression: a systematic review and meta-analysis. Pediatr Dent 41:88–94
Gomes I, Moura P, Gomes G, Perdigão J (2006) Localized discoloration of central incisors: a case report. Pract Proced Aesthet Dent 18:656–660
Knösel M, Eckstein A, Helms HJ (2019) Long-term follow-up of camouflage effects following resin infiltration of post orthodontic white-spot lesions in vivo. Angle Orthod 89:33–39
Meyer-Lueckel H, Moser C, Wierichs RJ, Lausch J (2022) Improved surface layer erosion of pit and fissure caries lesions in preparation for resin infiltration. Caries Res 56:496–502
Paris S, Meyer-Lueckel H (2009) Masking of labial enamel white spot lesions by resin infiltration--a clinical report. Quintessence Int 40:713–718
Perdigão J (2020) Resin infiltration of enamel white spot lesions: an ultramorphological analysis. J Esthet Restor Dent 32:317–324
Robinson C, Hallsworth AS, Weatherell JA, Künzel W (1976) Arrest and control of carious lesions: a study based on preliminary experiments with resorcinol-formaldehyde resin. J Dent Res 55:812–818

Part IV

Restorative Clinical Cases Involving Dental Bleaching

Direct Composite Resin Veneers After Periodontal Surgery and At-Home Bleaching

13

Edson Araujo

Abstract

The amount of gingiva and tooth visible during smiling reflects on the diagnostic evaluation of the patient's smile. A multidisciplinary team is often required to restore the esthetics and harmony of the smile zone. In the present case, the interaction between periodontal and esthetic dentistry specialists was utilized to solve the complexity of the case while respecting biological, functional, and esthetic principles.

13.1 Clinical Case (Figs. 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, and 13.8)

A 19-year-old patient was not happy with the color of the teeth ("too dark and yellowish") in addition to the shape and size of the maxillary lateral incisors. The treatment plan involved esthetic periodontal surgery on teeth #7 (FDI 1.2) and #10 (FDI 2.2) followed by at-home bleaching with 10% carbamide peroxide gel in a custom-fitted tray and recontouring the teeth with resin composite.

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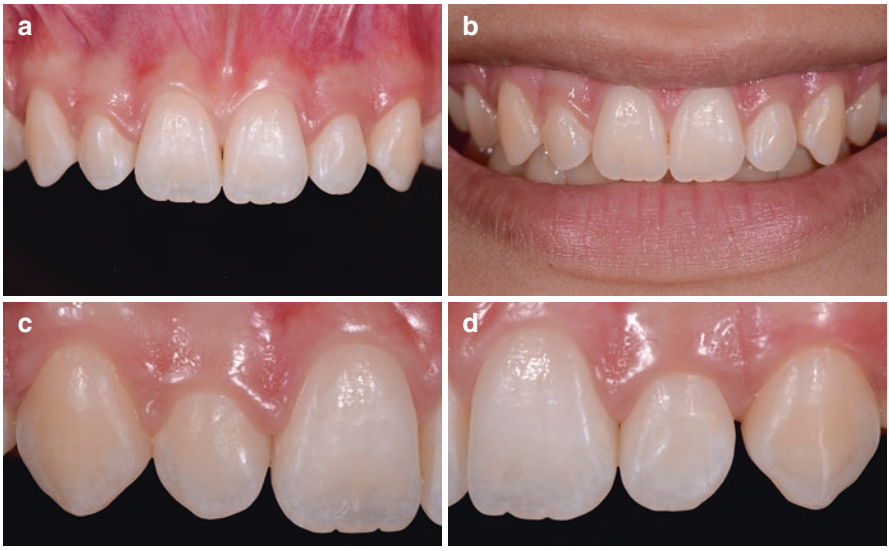

Fig. 13.1 Preoperative view. Note the lack of harmony as a result of the color of the teeth, the inadequate morphology of the lateral incisors, and the deficient contour, volume and height of the gingival tissue around the same teeth. (**a**) Retracted view on the maxillary anterior teeth; (**b**) Smile line denoting the lack of harmony of the lateral incisors; (**c**) Close-up view of the right maxillary lateral incisor; (**d**) Close-up view of the left maxillary lateral incisor

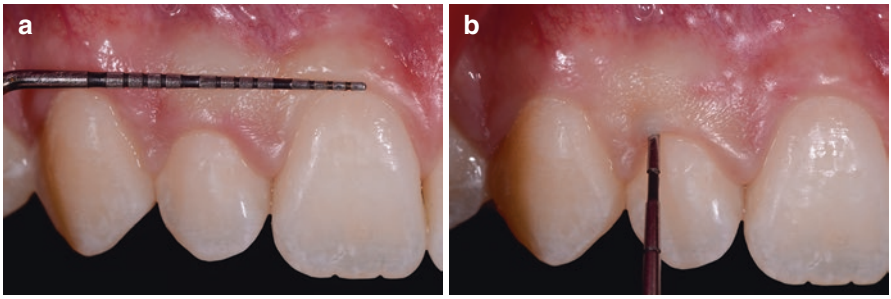

Fig. 13.2 (**a**) Periodontal probe positioned over the gingival zenith of teeth #6 (FDI 1.3) and #8 (FDI 1.1) to define the height of the new planned gingival zenith of tooth #7 (FDI 1.2). (**b**) The periodontal probe is properly positioned to measure the depth of the gingival sulcus of tooth #7 (FDI 1.2). This step is essential to define whether an osteoplasty will be necessary in addition to gingivoplasty

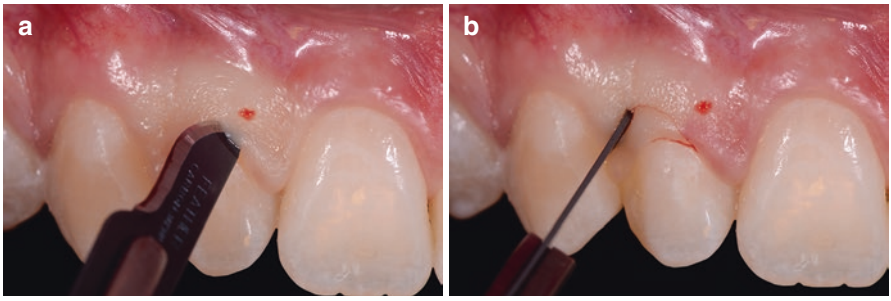

Fig. 13.3 (**a**, **b**) Sequential photographs during the surgical incision to obtain a new gingival contour

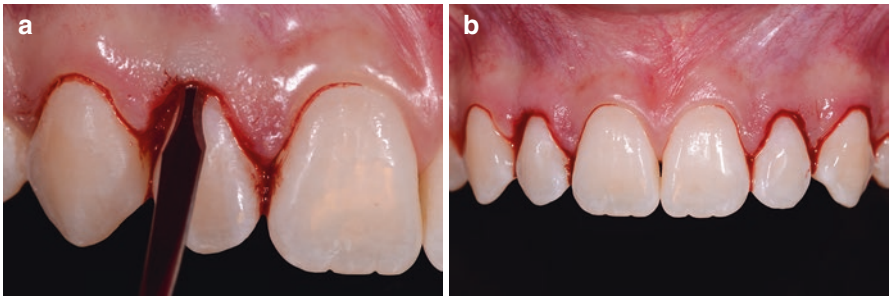

Fig. 13.4 (**a**) Osteotomy with periodontal micro chisel. (**b**) After the periodontal surgery. *Special thanks to Dr. Rodrigo Barbosa Lima who performed the periodontal surgery and respective follow-up*

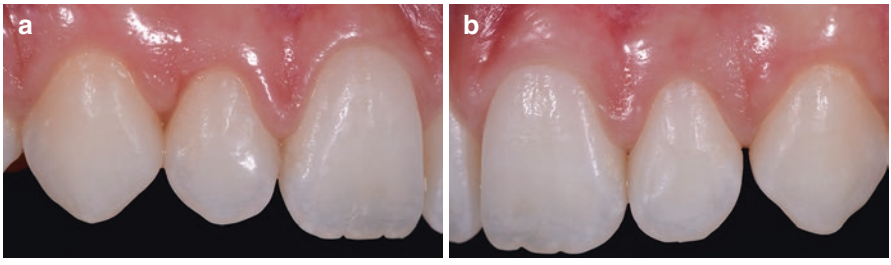

Fig. 13.5 Results shown 6 weeks after the periodontal surgery. (**a**) Close-up view of the right maxillary lateral incisor; (**b**) Close-up view of the left maxillary lateral incisor

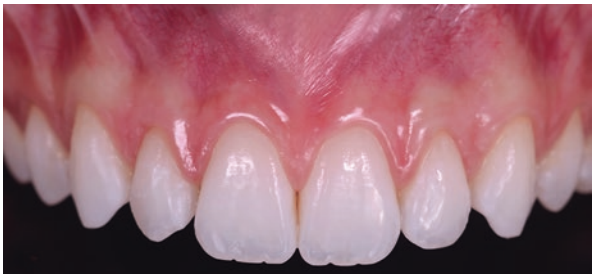

Fig. 13.6 After 3 weeks of at-home bleaching with 10% carbamide peroxide gel in a custom-fitted tray (Opalescence 10%, Ultradent Products, South Jordan, UT, USA)

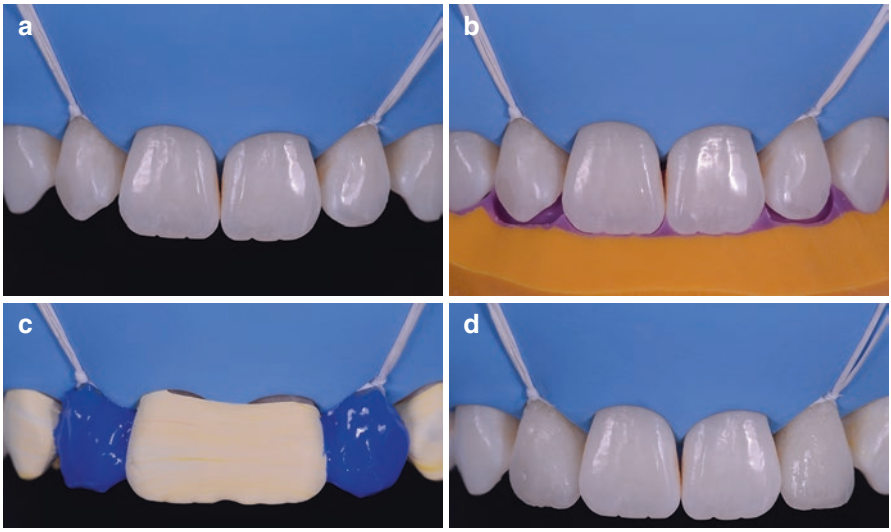

Fig. 13.7 The restorative part of the treatment was carried out using a stratification technique 2 weeks after the patient finished the bleaching treatment. (**a)** Rubber dam isolation. (**b)** Matrix made with VPS (vinyl polysiloxane) impression material from a waxed-up model to define the new anatomy of the lateral incisors. (**c)** Enamel acid etching with 35% phosphoric acid for 15 s with agitation. (**d)** Scotchbond Universal Adhesive was used prior to Filtek Supreme Ultra composite resin (3M Oral Care, St. Paul, MN, USA)

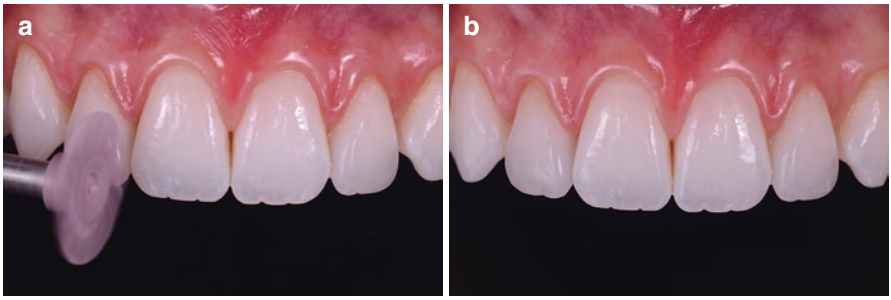

Fig. 13.8 (**a**) Restorations were finished with Sof-Lex XT discs and Finishing & Polishing Spiral Wheels (3M Oral Care). (**b**) Patient was extremely satisfied with the outcome

Internal Bleaching and Direct Composite Veneer

14

Edson Araujo and Renato Quirino Ramos

Abstract

Internal discoloration is the primary indication for bleaching root-filled teeth. The walking bleach technique (Chapter 8) uses a mixture of sodium perborate and distilled water that is left sealed inside the pulp chamber for periods of one week. This technique is still considered the standard treatment for intracoronal bleaching because it is a conservative alternative to the more invasive options such as full-coverage restorations. Other bleaching techniques for root-filled teeth have become more popular. Carbamide peroxide (≈ 35%) and 35% hydrogen peroxide have been reported to be equally effective and not significantly different from the bleaching outcomes provided by the walking bleach technique with 35% hydrogen peroxide mixed with sodium perborate. The clinical case described in this chapter used a novel bleaching approach for discolored root-filled teeth. A 35% hydrogen peroxide gel indicated for in-office external bleaching of vital teeth was used intracoronally in 3 weekly sessions using the same protocol indicated for in-office bleaching. Tooth #9 (FDI 2.1) was restored with a multilayered composite resin veneer.

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14.1 Clinical Case

A 31-year-old patient was very dissatisfied with the appearance of her smile (Fig. 14.1a, b). The presence of a darkened tooth (#8; FDI 1.1) and an esthetically unacceptable composite resin veneer on tooth #9 (FDI 2.1) were observed during the clinical exam. Large composite resin restorations (mirror images) were observed from the palatal aspect (Fig. 14.1c). Both teeth had been root canal treated for over 5 years. The radiographic exam did not show any areas of concern.

After removing the restorations to carry out an internal bleaching procedure, we noticed an extensive area of undermined enamel (Fig. 14.2a). Internal whitening (Fig. 14.2b) was performed in 3 weekly sessions using 35% hydrogen peroxide (Whiteness HP Blue, FGM, Joinville, SC, Brazil). Figure 14.2c depicts the outcome 1 week after the third application of the bleaching agent.

After careful removal of the composite resin veneer from tooth #9 (FDI 2.1), a restorative mock-up was carried out using several composite resin shades and translucencies as well as different pigments to be used in the fabrication of the restoration (Fig. 14.3). The patient approved the shape and color of the mock-up.

Teeth #8 (FDI 1.1) and #9 (FDI 2.1) were restored under modified isolation (Fig. 14.4). A ribbon made of polytetrafluoroethylene tape was inserted in the gingival sulcus of tooth #9 (FDI 2.1) to control the crevicular fluid flow and to avoid contamination during the restorative procedure.

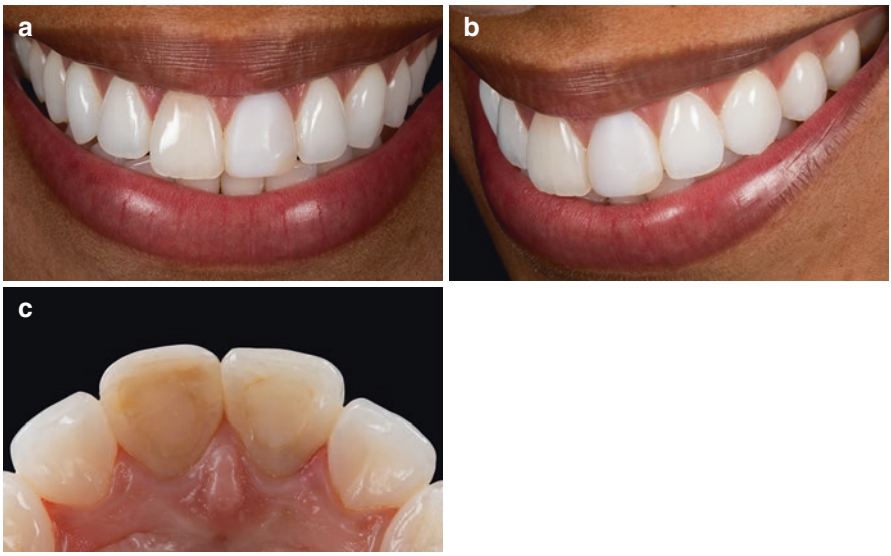

Fig. 14.1 (**a** and **b**) Preoperative view denoting discoloration of tooth #8 (FDI 1.1) and an opaque composite resin veneer on tooth #9 (FDI 2.1). (**c**) Both teeth had large composite resin restorations on the palatal surfaces

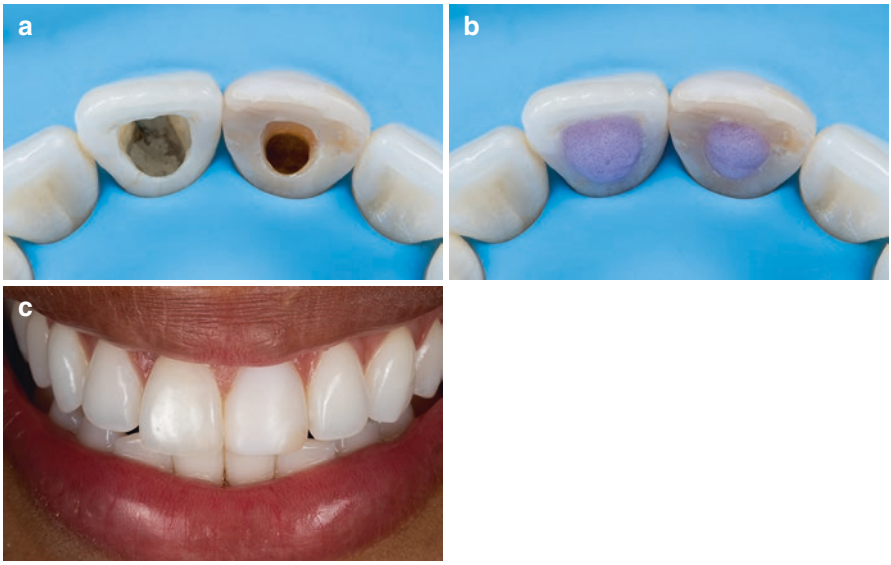

Fig. 14.2 (**a**) We found an extensive area of undermined enamel after removing the restorations to carry out the internal bleaching procedure. (**b**) Internal whitening with 35% hydrogen peroxide gel in 3 weekly sessions. (**c**) Clinical outcome 1 week after the third application of the bleaching agent

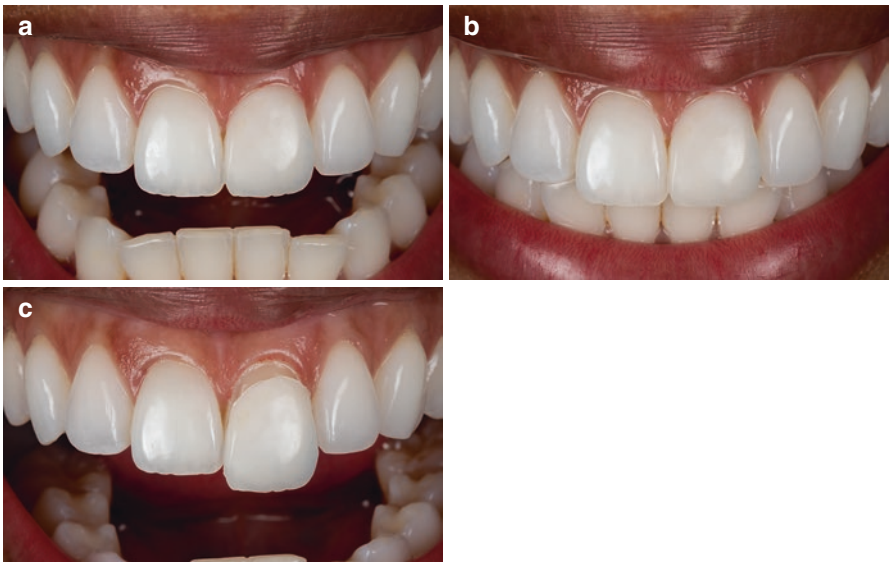

Fig. 14.3 Upon removal of the composite resin veneer on tooth #9 (FDI 2.1), a mock-up was built using several composite resin shades as well as different pigments. (**a**) and (**b**) Analysis of composite resin veneer mock-up to evaluate the esthetic outcome. (**c**) Removal of the mock-up to visualize the contrast with the underlying tooth structure

A 3-step etch-and-rinse adhesive system (OptiBond FL, Kerr, Brea, CA, USA) was used for both restorations. The palatal surface of teeth #8 (FDI 1.1) and #9 (FDI 2.1) was restored with Empress Direct, shade BL-L Dentin (Ivoclar Vivadent, Schaan, Liechtenstein).

The labial restoration of tooth #9 (FDI 2.1) was carried out as described below:

1. A dentin-shaded composite resin (Estelite Omega, shade BL2, Tokuyama Dental Corp., Tokyo, Japan) was used to mask the darkened substrate (Fig. 14.4b).
2. A translucent composite resin (Estelite Omega, shade Trans, Tokuyama Dental Corp.) was used to create the appearance of translucency of the incisal edge (Fig. 14.4c).
3. A series of pigments was applied to highlight certain effects in the restoration. The pigment OptiGlaze color ivory white (GC Corp., Tokyo, Japan) was used to emphasize the opaque incisal halo (Fig. 14.4d, e).
4. The pigment OptiGlaze color blue (GC Corp.) was applied to create a translucency effect between the mamelons (Fig. 14.4f, g).
5. The pigment OptiGlaze color pink (GC Corp.) was applied to mimic the counter-opalescence effect (Fig. 14.4h, i).
6. The pigment OptiGlaze color olive (GC Corp.) was used to increase the saturation of the cervical third of the restoration (Fig. 14.4j, k).
7. To finish the restoration, an enamel layer (Estelite Omega, shade Milky-White, Tokuyama Dental Corp.) was applied to the buccal surface. The immediate final appearance is seen in Fig. 14.4l.
8. A #15 blade was used to create a craze line in the restoration to mimic the characteristics of the buccal surface of tooth #8 (FDI 1.1) (Fig. 14.4m).
9. The result after finishing and final polishing of the restorations is shown in Fig. 14.5.

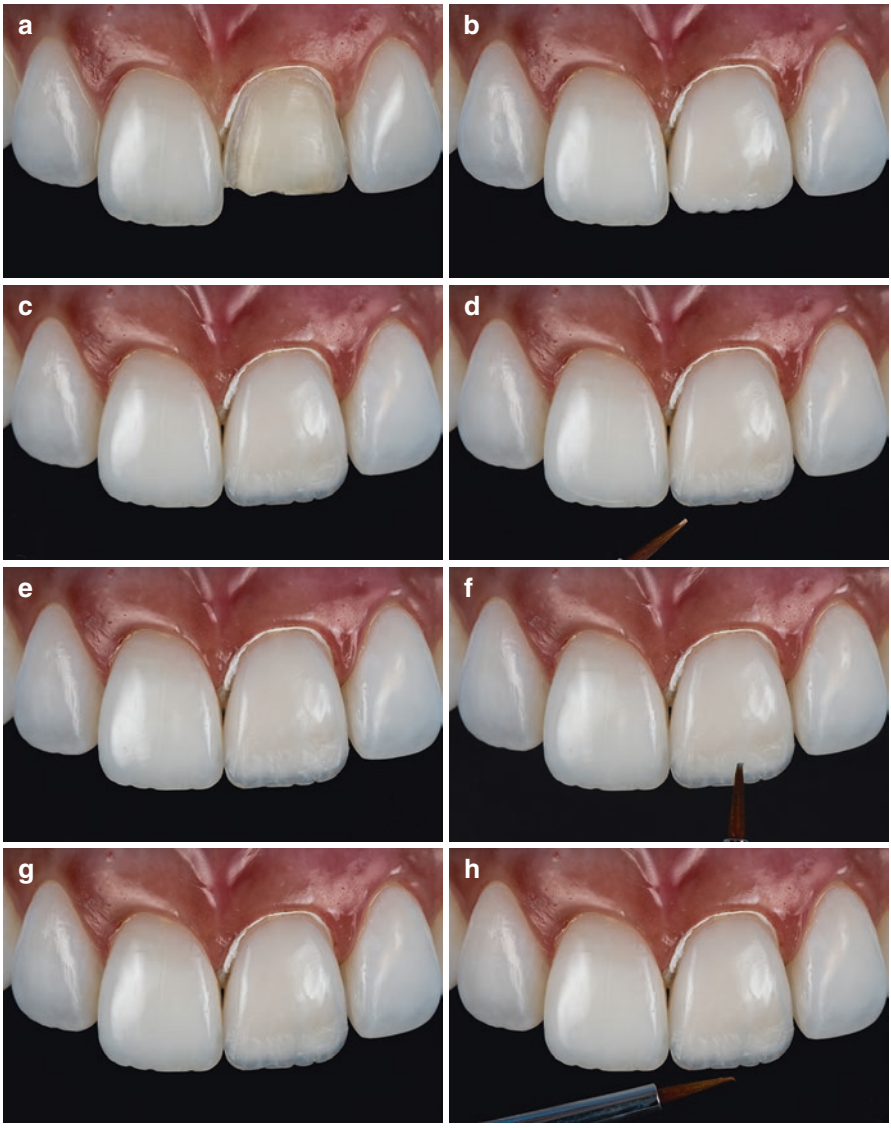

Fig. 14.4 (**a**) A ribbon made of polytetrafluoroethylene tape was inserted in the gingival sulcus of tooth #9 (FDI 2.1) to mimic a retraction cord. (**b**) A dentin-shaded composite resin was used to mask the darkened dentin. (**c**) A translucent composite resin was used to create the appearance of translucency of the incisal edge. (**d** and **e**) A series of pigments was applied to highlight some effects in the restoration. A white-colored pigment was used to emphasize the opaque incisal halo. (**f** and **g**) A blue-colored pigment was applied to create a translucency effect between the mamelons. (**h** and **i**) A pink-colored pigment was applied to mimic the counter-opalescence effect. (**j** and **k**) An olive-colored pigment was used to increase the saturation of the cervical third of the restoration. (**l**) An enamel-shaded composite resin was applied to the buccal surface. (**m**) A #15 blade was used to create a craze line to mimic the anatomy of tooth #8 (FDI 1.1)

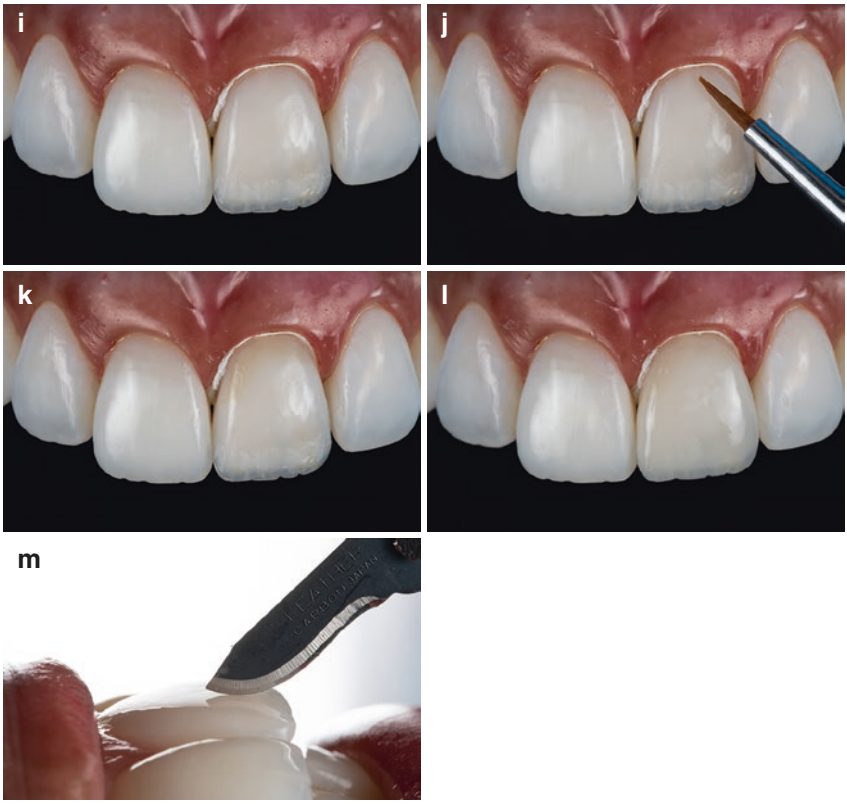

Fig. 14.4 (continued)

Fig. 14.5 After finishing and polishing the restorations. (**a**) Unretracted functional view of the final restoration. (**b**) and (**c**) Retracted views depicting the esthetic outcome

Internal/External Bleaching and Direct/Indirect Composite Restorations

15

Elaine Vilela Maia and Rogério Almeida Geraldino

Abstract

The restoration of anterior teeth using dental adhesives and composite resins is one the most common restorative treatments in general practice. The color and translucency of the tooth substrate play a very important role in the esthetic outcome of these anterior composite restorations. For this reason, pre-restorative dental bleaching is recommended in clinical cases in which the optical characteristics of the substrate may compromise the esthetic result of the restorative procedure.

15.1 Clinical Case 1

A 27-year-old patient sought dental care "to improve the overall color of the teeth and remove the white stain" on tooth #9 (FDI 2.1). The patient was also "concerned with the color of the filling" on tooth #8 (FDI 1.1) (Fig. 15.1). After clinical and radiographic exams, pulp sensitivity tests were performed on the maxillary incisors. All teeth responded to cold within normal limits.

The first step of the proposed treatment included at-home bleaching in a custom-made tray with 10% carbamide peroxide gel (Polanight, SDI Limited, Bayswater, Australia) for 4–5 weeks. Patient returned to the clinic after 5 weeks (Fig. 15.2). The shade of her teeth had lightened from shade A3 to B1 (Vita Classical A1–D4 shade

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J. Perdigão (ed.), *Tooth Whitening*, https://doi.org/10.1007/978-3-031-38244-4_15

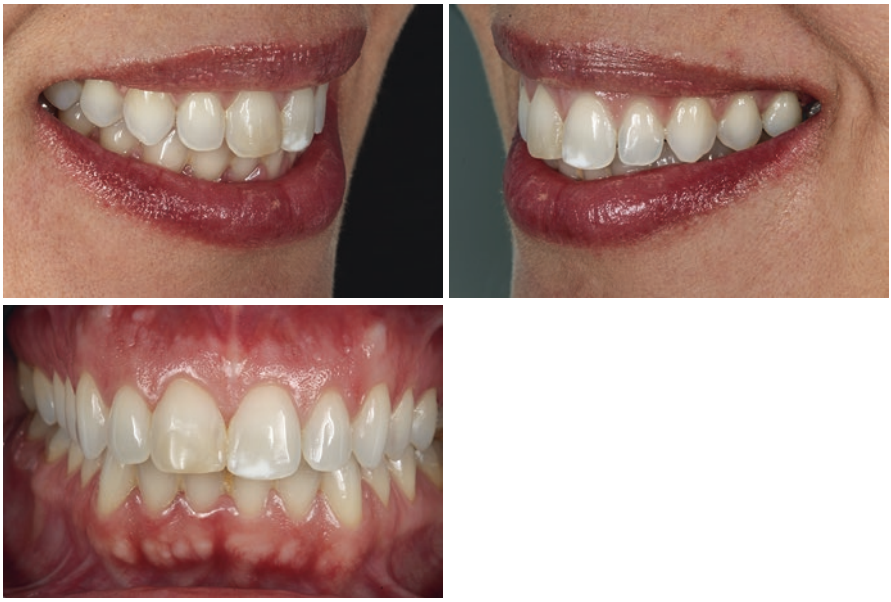

Fig. 15.1 Preoperative view denoting a dark composite resin restoration on tooth #8 (FDI 1.1) and an enamel white spot lesion on tooth #9 (FDI 2.1). Patient was not pleased with the overall color of the teeth

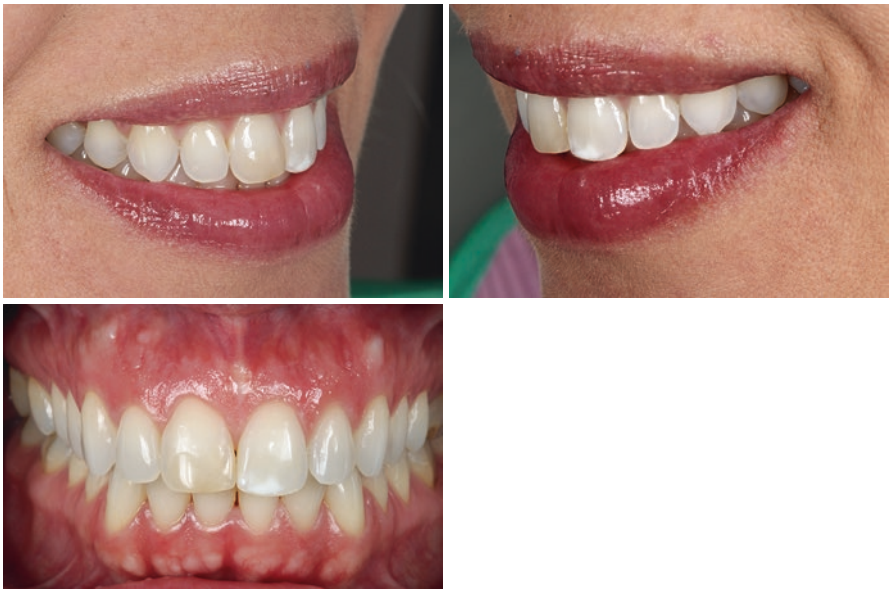

Fig. 15.2 After at-home whitening for 5 weeks using 10% carbamide peroxide in a custom-made bleaching tray

Fig. 15.3 The restoration of tooth #8 (FDI 1.1) was replaced 2 weeks after the final at-home bleaching treatment. The white spot lesion of tooth #9 (FDI 2.1) was removed, and the area was restored with a two-step etch-and-rinse adhesive and composite resin

guide, VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany). The size of the white spot area of tooth #9 (FDI 2.1) had slightly decreased; however, it was still very opaque.

The existing restoration of tooth #8 (FDI 1.1) was replaced 2 weeks after the patient finished the bleaching treatment. The restorative procedure included the two-step etch-and-rinse adhesive Adper Single Bond Plus (3M Oral Care, St. Paul, MN, USA), followed by the composite resins Aura (SDI Limited) shades DC1, DC2, and E1 and Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein) shades Trans 20 and Trans Opal (Fig. 15.3).

The white spot lesion of tooth #9 (FDI 2.1) was deemed too deep to be treated with resin infiltration. The hypocalcified enamel was removed and the area restored with the two-step etch-and-rinse adhesive Adper Single Bond Plus (3M Oral Care,) followed by the composite resin Aura (SDI Limited) shades DC2 and E1 (Fig. 15.3).

15.2 Clinical Case 2

This 32-year-old patient wanted to bleach his teeth and "do something about the dark incisor" (Fig. 15.4). Tooth #9 (FDI 2.1) had been endodontically treated for approximately 10 years. The respective root canal treatment was considered successful both radiographically and clinically.

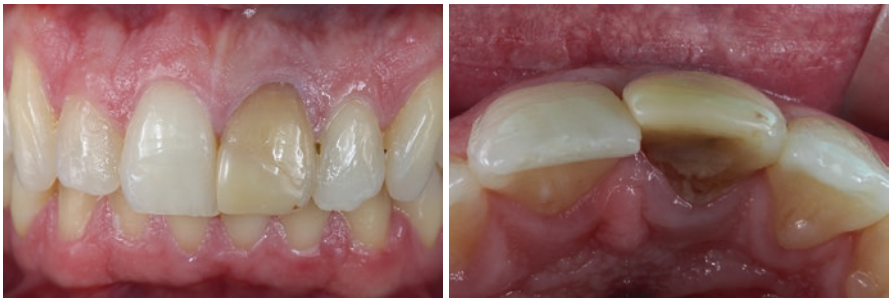

Fig. 15.4 Preoperative view of tooth #9 (FDI 2.1) that became darker after the root canal treatment

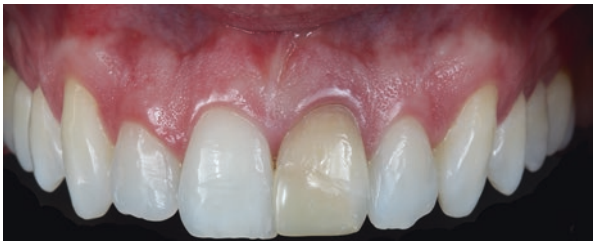

Fig. 15.5 Internal bleaching of tooth #9 (FDI 2.1) was carried out with 7.5% hydrogen peroxide for 2 weeks. All teeth were then bleached for 3 weeks overnight with 10% carbamide peroxide with potassium nitrate and sodium fluoride in a custom-fitted tray

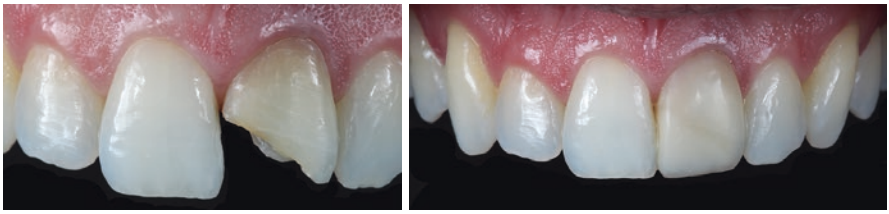

Fig. 15.6 The existing restoration was replaced 2 weeks after finishing the bleaching treatment

The treatment plan included internal bleaching of tooth #9 (FDI 2.1) with 7.5% hydrogen peroxide (White Class*, FGM, Joinville, SC, Brazil) for 2 weeks; however, the treatment was not very successful. All teeth were then bleached overnight for 3 weeks with 10% carbamide peroxide gel with potassium nitrate and sodium fluoride (Whiteness Perfect, FGM) in a custom-fitted tray (Fig. 15.5).

The existing restoration of tooth #9 (FDI 2.1) was replaced 2 weeks after finishing the bleaching treatment (Fig. 15.6). Three weeks later the tooth was prepared for an indirect composite veneer. The preparation was deep enough to allow for the

stratification of composite resins to mask the darker background (Fig. 15.7). The patient did not want a ceramic veneer for financial reasons.

The indirect composite veneer was fabricated directly on the tooth. After refining the tooth preparation, a layer of Filtek Z350XT** (3M Oral Care) shade A1D was inserted and light cured, followed by Empress Direct (Ivoclar Vivadent) shades EBL-L. An excess was left around the cervical area to allow for a better fit during the cementation procedure. The composite resin was light cured. The indirect veneer was detached from the tooth, further light cured for 80 sec from each surface, and then finished and polished outside the mouth (Fig. 15.8).

The intaglio of the indirect composite veneer was sandblasted with aluminum oxide for 15 seconds and cemented with Adper Single Bond Plus (3M Oral Care)

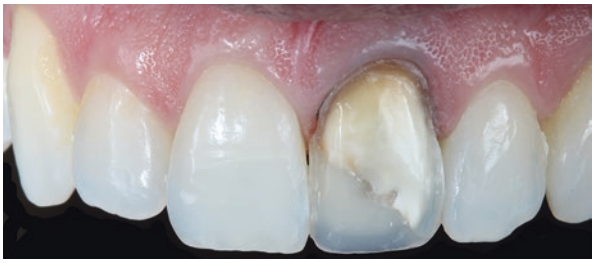

Fig. 15.7 Three weeks later the tooth was prepared for an indirect composite veneer

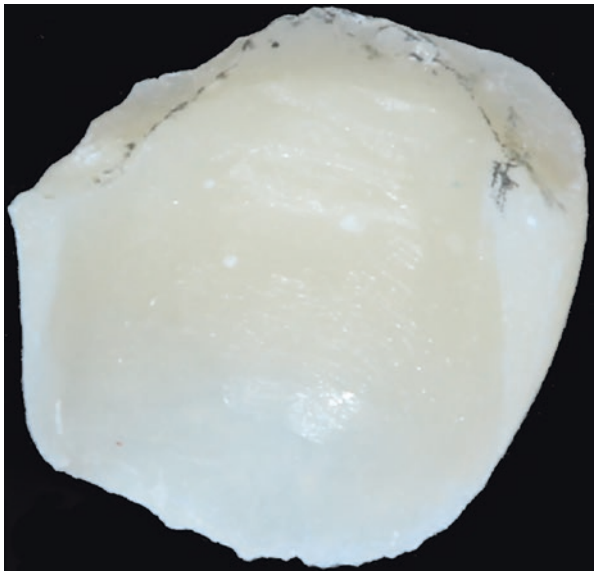

Fig. 15.8 The indirect composite veneer was fabricated directly on the tooth, finished outside the mouth, and cemented with a two-step etch-and-rinse adhesive followed by a flowable composite resin

and Tetric Flow (Ivoclar Vivadent) shade A1. The restoration was finished and polished with Sof-Lex discs (3M Oral Care) (Fig. 15.9).

*Also available as Wīt Essential Xtra, FGM Dental Group, Fort Lauderdale, FL, USA.

**Also available as Filtek Supreme Ultra or Filtek Supreme XTE in other regions of the world.

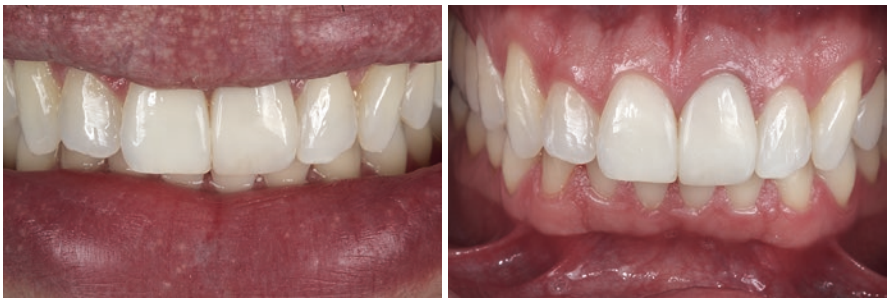

Fig. 15.9 Final restoration after finishing and polishing

At-Home Bleaching and Direct Composite Restorations

16

George Gomes, Filipa Oliveira, and Jorge Perdigão

Abstract

The esthetic enhancement of the anterior teeth may benefit from at-home bleaching prior to esthetic rehabilitation or prior to recontouring clinical crowns with direct resin-based composite restorations. This clinical case illustrates the treatment details of a patient who wanted to change the color and the shape of her anterior teeth.

16.1 Introduction

At-home bleaching with carbamide peroxide gel in a custom-fitted tray is a very effective method to lighten the intrinsic color of teeth and to remove external stains from the tooth surface. When the treatment plan involves dental bleaching followed by direct resin composite bonding procedures (recontouring anterior teeth, direct resin composite veneers, bonding orthodontic brackets, among others), the dental professional must take into consideration that enamel and dentin bond strengths remain low for the first 2 weeks post-bleaching. For enamel specifically, 10% carbamide peroxide reduces the bond strengths of resin-based composite to etched enamel (Cvitko et al. 1991; Barghi and Godwin 1994; Ben-Amar et al. 1995;

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Spyrides et al. 2000) and increases enamel surface porosity (Ben-Amar et al. 1995). This reduction may be as high as 76% of the bond strengths to unbleached enamel (Spyrides et al. 2000).

After a lapse of 2 weeks, the bond strengths return to the level of untreated substrates (Cavalli et al. 2001; Shinohara et al. 2005). A minimum waiting period of 2 weeks is recommended after the patient completes the whitening treatment prior to performing any adhesive restorative procedure. In case the patient is unable to wait for 2 weeks, it has been shown that removal of surface enamel prior to bonding restores enamel bond strengths to normal level (Cvitko et al. 1991). The use of acetone-based adhesives or drying agents, such as 70% alcohol and acetone, may also restore bond strength of composite resin to enamel immediately after bleaching (Barghi and Godwin 1994; Niat et al. 2012).

This chapter illustrates a combined technique in which at-home bleaching of both arches with 10% carbamide peroxide in a custom-fitted tray was first completed, followed by direct resin composite for recontouring the anterior teeth.

16.2 Technique

A 34-year-old patient called the dental office to set up an appointment primarily because she was concerned about the "how short her upper front teeth were." Additionally, the patient "wanted to have whiter teeth."

During the appointment the patient did not mention any other issues with the anterior teeth. The patient just wanted to improve the esthetics of her maxillary anterior teeth to change the appearance of her smile (Fig. 16.1). The clinical examination revealed no discomfort during function. The temporomandibular joint was asymptomatic. Upon clinical and radiographic exam, the treatment plan presented to patient included at-home bleaching with 10% carbamide peroxide with potassium nitrate and sodium fluoride in a custom-fitted tray overnight for 2 weeks, followed by recontouring the incisal edges of the maxillary incisors with direct resin-based composite resin. We also suggested the correction of the buccal mesial line angle of tooth # 9 (FDI 2.1) and adjustment of the length of the maxillary

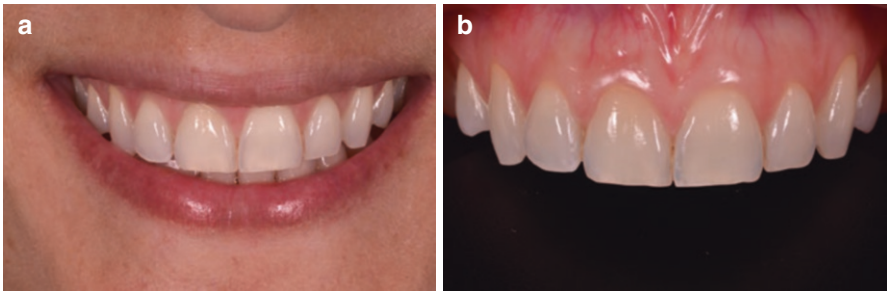

Fig. 16.1 (**a**) Preoperative view of patient's smile. (**b**) Preoperative view of patient's maxillary anterior teeth. Note the reduced length of the anterior teeth

canines with direct resin-based composite. Patient agreed with the proposed treatment plan. Figures 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 16.10, 16.11, 16.12, 16.13, 16.14, 16.15, 16.16, 16.17, 16.18, and 16.19 show the treatment sequence step by step.

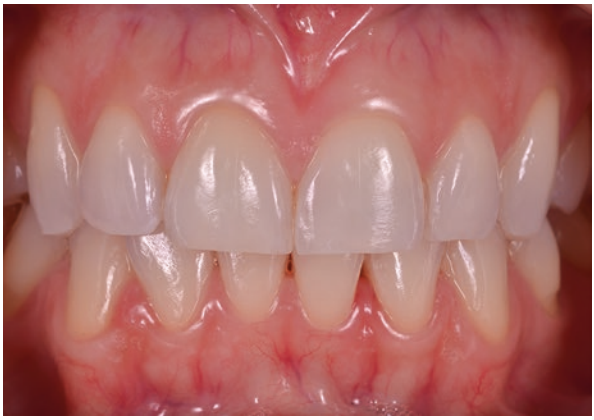

Fig. 16.2 Aspect of the anterior teeth after 14 days of at-home whitening. Patient was satisfied with the lighter color of her teeth

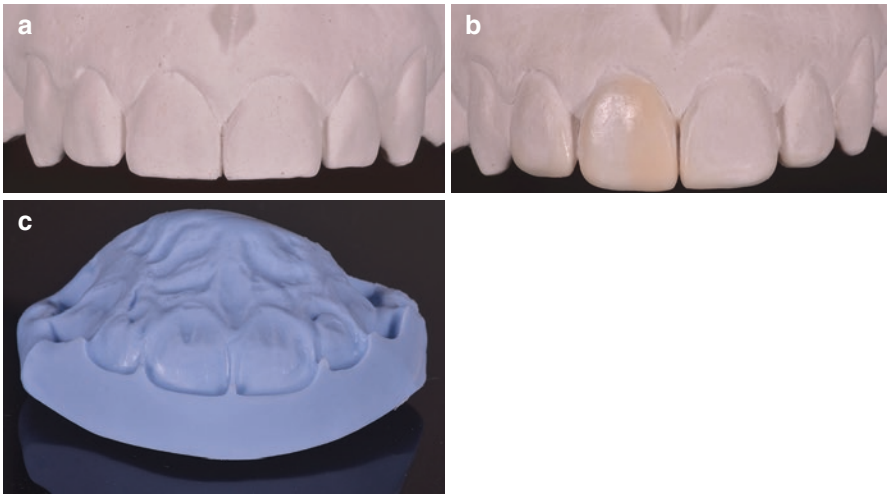

Fig. 16.3 (**a**) Stone model of the maxillary anterior teeth. (**b**) The stone model was waxed up to establish a harmonious length and shape of the anterior teeth. Patient was very happy with this blueprint of her teeth. (**c**) A matrix made of putty-consistency VPS (vinyl polysiloxane) impression material was prepared from the waxed-up model. This silicone index was used as guidance for the lingual contour and to establish the new incisal edge position

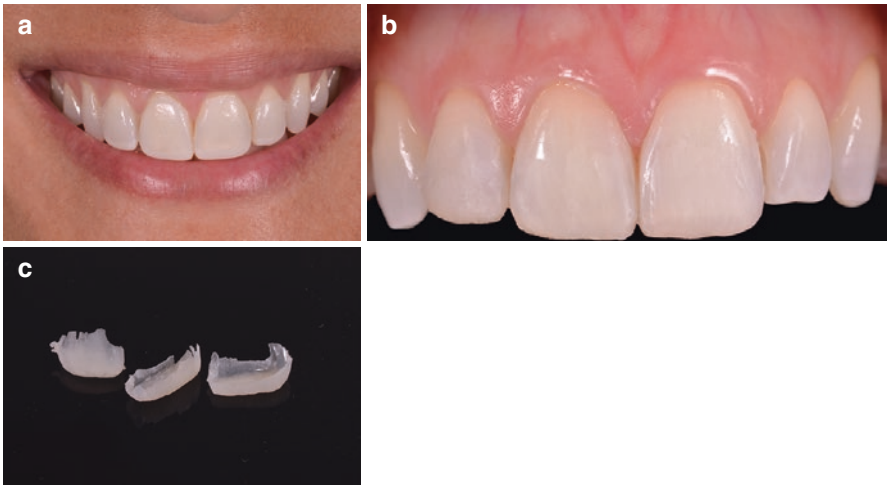

Fig. 16.4 (**a**) A mock-up was made with bis-acryl composite (Protemp 4, also known as Protemp Plus, 3M Oral Care, St. Paul, MN, USA) to allow the patient to foresee the esthetic outcome of the new restorations. (**b**) Diagnostic resin-based composite restorations were made prior to the adhesive procedure to verify the stratification and thickness of each composite layer and the color. (**c**) Diagnostic restoration upon removal

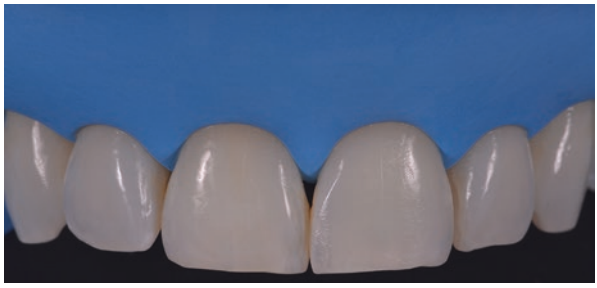

Fig. 16.5 The teeth were cleaned with a suspension of pumice and water and thoroughly washed with water. Area was isolated with rubber dam

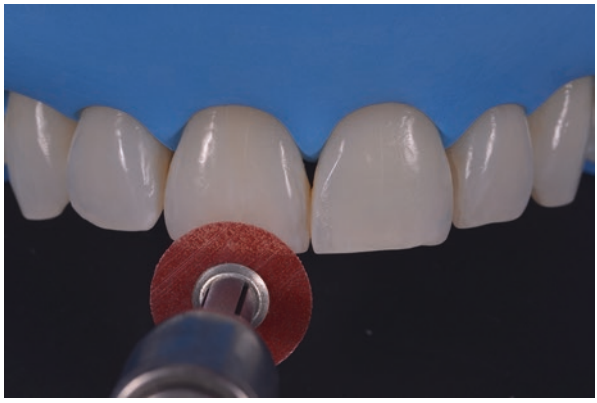

Fig. 16.6 Enamel was roughened with Sof-Lex discs (3M Oral Care)

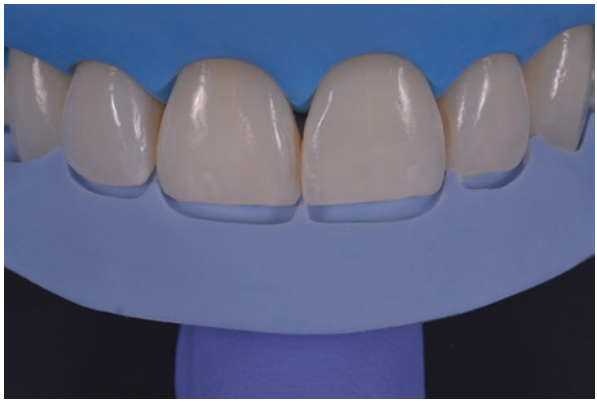

Fig. 16.7 The VPS matrix was tried-in

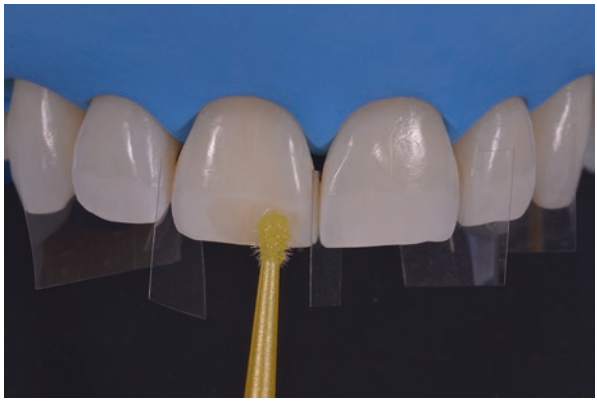

Fig. 16.8 The teeth were etched with 32% phosphoric acid (Scotchbond Universal Etchant, 3M Oral Care) for 15 s. The etchant was thoroughly rinsed for 20 s. The two-step etch-and-rinse adhesive Adper Single Bond Plus, also known as Adper Scotchbond 1 XT and Adper Single Bond 2, 3M Oral Care was vigorously applied for 15 s

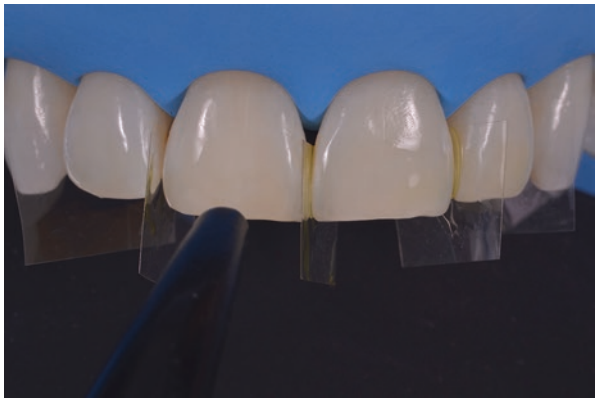

Fig. 16.9 The adhesive was gently air-dried to evaporate the solvent

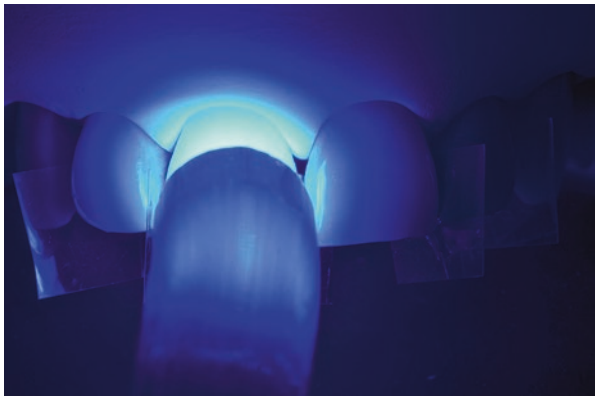

Fig. 16.10 The adhesive was light cured for 15 s

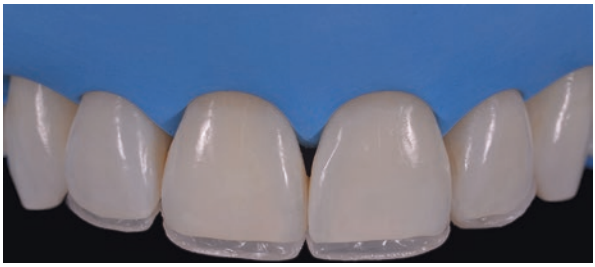

Fig. 16.11 A thin palatal (or lingual) layer of resin-based composite (Filtek Supreme Ultra, also known as Filtek Supreme XTE and Filtek Z350 XT, 3M Oral Care) was applied with the VPS matrix using shade B1B for the central incisors and shade B1E for the lateral incisors

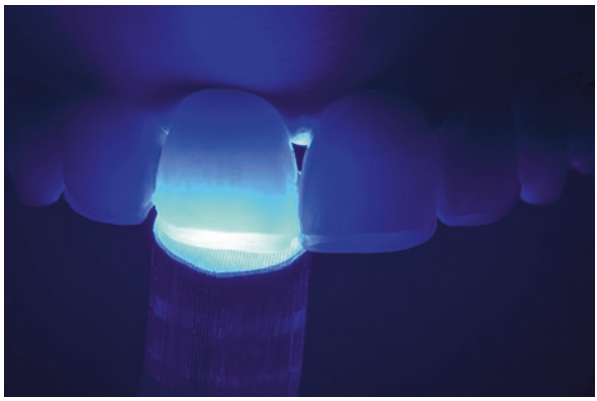

Fig. 16.12 This palatal enamel layer was light cured from buccal and from lingual for 40 s each

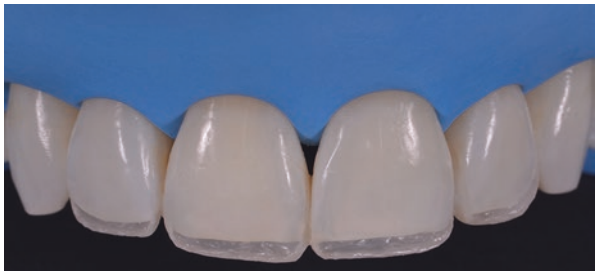

Fig. 16.13 The incisal opaque halo was replicated using shade A2D (central incisors) and shade B1B (lateral incisors), the same shades that had been used for the diagnostic restoration (Fig. 16.4c) as the dentin replacement shades

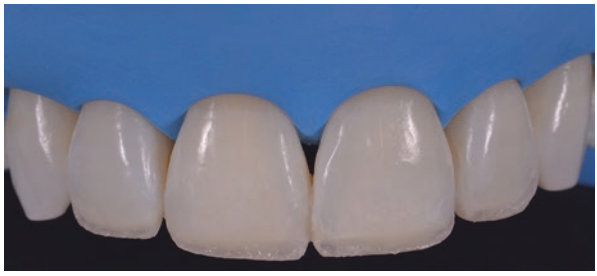

Fig. 16.14 After light curing the incisal opaque halo, the dentin layer was reproduced, leaving space for the opalescent layer. The dentin layer was light cured for 40 s

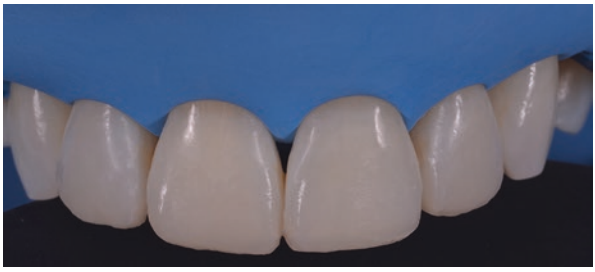

Fig. 16.15 An opalescent layer (shade AT or Amber Translucent) was applied between the A2D dentin replacement composite layer and the A2D incisal opaque halo. The enamel layer was reproduced using shade XWE for the central incisors and shade B1E for the lateral incisors. The restorations were light cured for 40 s each from buccal and lingual aspects

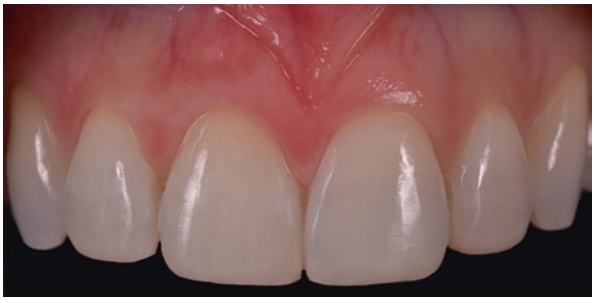

Fig. 16.16 Aspect of the restored teeth after polishing and removing the rubber dam

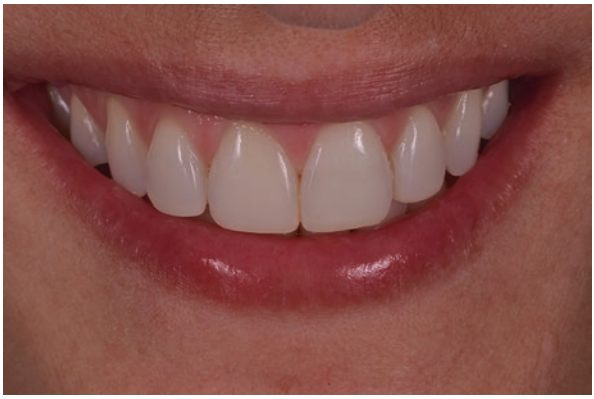

Fig. 16.17 Postoperative view of patient's smile

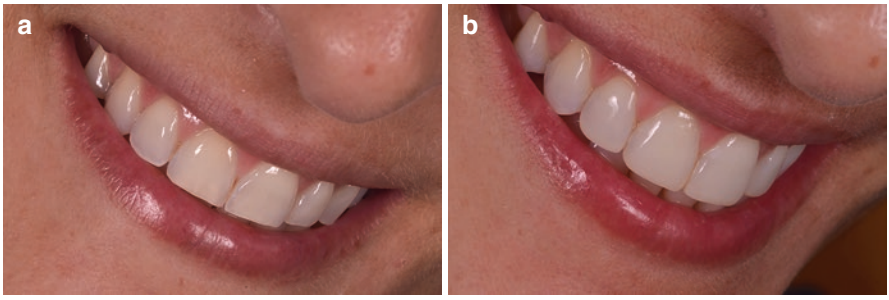

Fig. 16.18 (**a**) Preoperative right-side view of patient's smile. (**b**) Postoperative right-side view of patient's smile

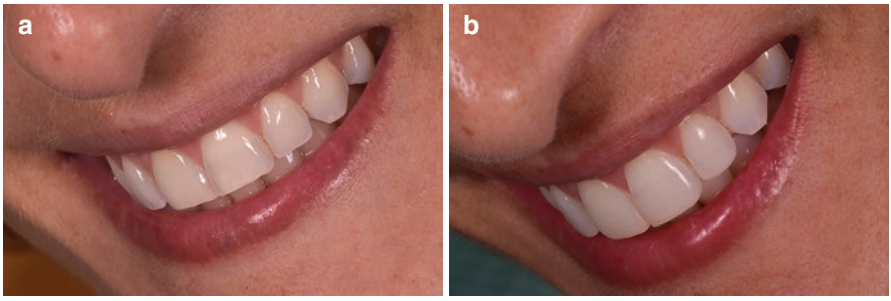

Fig. 16.19 (**a**) Preoperative left-side view of patient's smile. (**b**) Postoperative left-side view of patient's smile

References

Barghi N, Godwin JM (1994) Reducing the adverse effect of bleaching on composite-enamel bond. J Esthet Dent 6:157–161

Ben-Amar A, Liberman R, Gorfil C, Bernstein Y (1995) Effect of mouthguard bleaching on enamel surface. Am J Dent 8:29–32

Cavalli V, Reis AF, Giannini M, Ambrosano GM (2001) The effect of elapsed time following bleaching on enamel bond strength of resin composite. Oper Dent 26:597–602

Cvitko E, Denehy GE, Swift EJ Jr, Pires JA (1991) Bond strength of composite resin to enamel bleached with carbamide peroxide. J Esthet Dent 3:100–102

Niat AB, Yazdi FM, Koohestanian N (2012) Effects of drying agents on bond strength of etch-and-rinse adhesive systems to enamel immediately after bleaching. J Adhes Dent 14:511–516

Shinohara MS, Peris AR, Pimenta LA, Ambrosano GM (2005) Shear bond strength evaluation of composite resin on enamel and dentin after nonvital bleaching. J Esthet Restor Dent 17:22–29

Spyrides GM, Perdigao J, Pagani C, Araújo MA, Spyrides SM (2000) Effect of whitening agents on dentin bonding. J Esthet Dent 12:264–270

Dental Bleaching as an Adjuntive Treatment in Prosthodontics

17

Diego Klee de Vasconcellos and Edson Araujo

17.1 Implant Crown, At-Home Bleaching, and Composite Veneers

Dental bleaching has been considered an important adjunctive treatment in Prosthodontics (Haywood and Al Farawati 2019). The first clinical case describes the situation of a patient with a history of avulsion of tooth #10 (FDI 2.2) in an automobile accident (Fig. 17.1). The treatment plan (Figs. 17.2, 17.3, and 17.4) included an osseointegrated implant and bone graft (Figs. 17.5 and 17.6). The osseointegrated implant was inserted* (Maestro 3.5/11 mm, Implacil De Bortoli, São Paulo, SP, Brazil), and an alloplastic bone graft was performed on the buccal surface (Bio-Oss Collagen, Geistlich Pharma AG, Wolhusen, Switzerland) with the aim of regenerating this region and reducing the depression caused by the dental avulsion. A CAD-CAM provisional crown (Fig. 17.7) was made of PMMA using the screw-retained technique to facilitate its removal and replacement without the need for temporary cements.

At-home bleaching of the other teeth was performed with Opalescence 10% PF (10% carbamide peroxide with potassium nitrate and sodium fluoride, Ultradent Products, Inc., South Jordan, UT, USA) for 3 weeks overnight. Two weeks after finishing the bleaching treatment, the esthetics of the anterior segment was enhanced (Fig. 17.8) with direct composite restorations using the dentin adhesive OptiBond FL (Kerr, Brea, CA, USA) and composite resin Essentia (GC Corp., Tokyo, Japan).**

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J. Perdigão (ed.), *Tooth Whitening*, https://doi.org/10.1007/978-3-031-38244-4_17

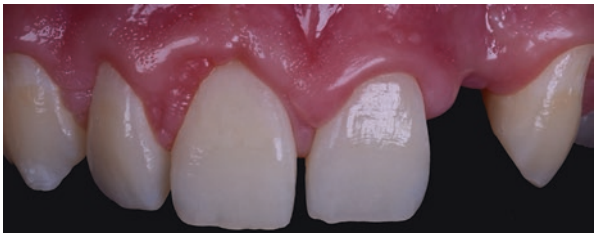


Fig. 17.1 Frontal view of the maxillary anterior teeth. Patient with a history of avulsion of tooth #10 (FDI 2.2) in an automobile accident

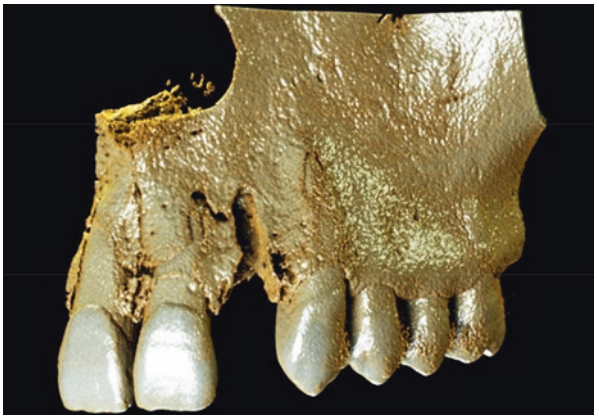
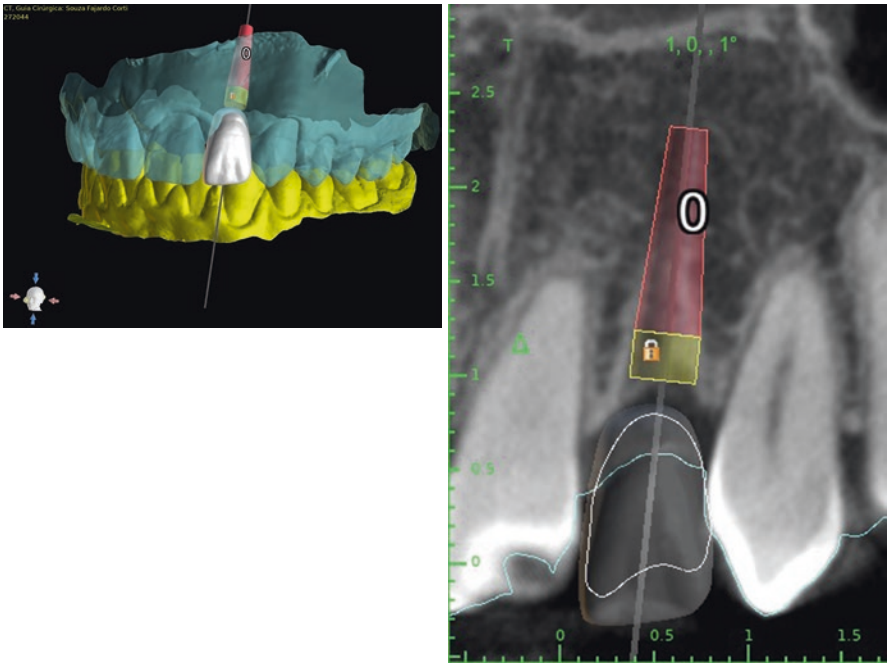
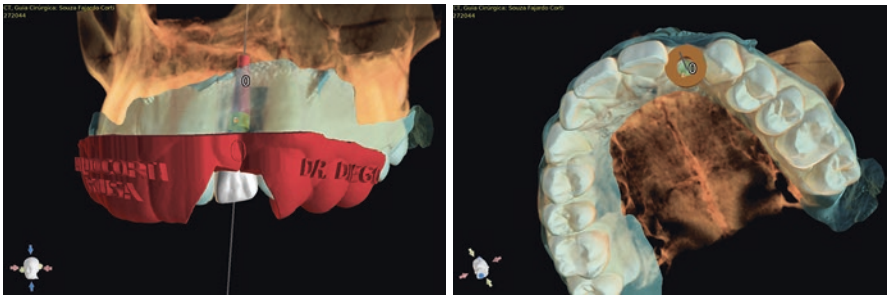


Fig. 17.2 Tomographic exam showing the loss of part of the buccal bone plate of this tooth, which resulted in a challenging situation for the placement of an osseointegrated implant



Figs. 17.3 Virtual planning to determine the best three-dimensional positioning of the implant



Figs. 17.4 The surgical guide is designed to be sent for 3D printing

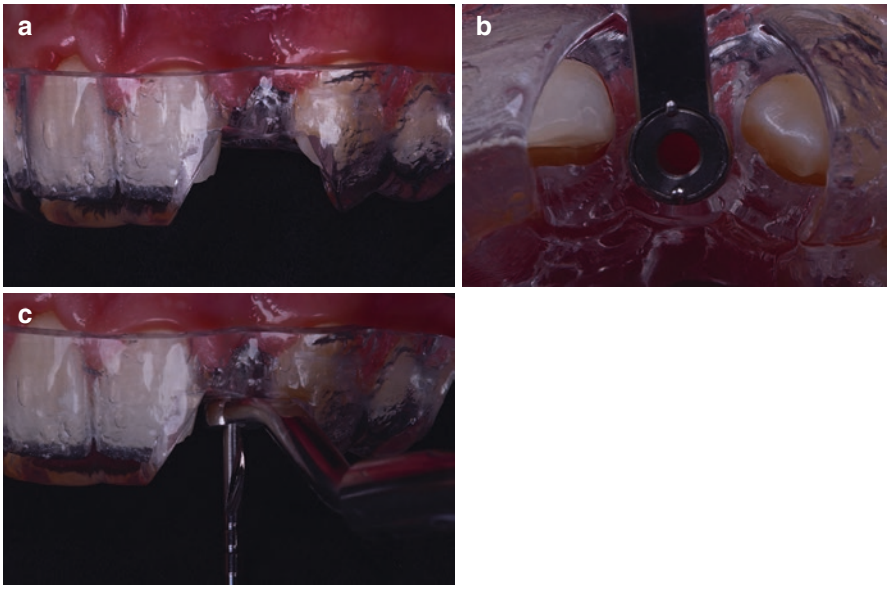


Fig. 17.5 (**a**, **b**) Trying in the printed guide. (**c**) Guided bone milling for insertion of the osseointegrated implant

A single-body solid prosthetic abutment was selected and installed (Abutment Ideale – Implacil De Bortoli). A scanning body (Exocad Digital Transfer – Implacil De Bortoli) was positioned on the prosthetic abutment, enabling intraoral scanning (Cerec AC Omnicam, Dentsply Sirona, Charlotte, NC, USA) (Fig. 17.9).

The final bilayered ceramic crown (Fig. 17.10) was fabricated*** using 3Y-TZP, (Zolid Zirconia, Amann Girrbach AG, Koblach, Austria) as the coping, veneered with feldspathic ceramic (Vita VM9, VITA Zahnfabrik, Bad Säckingen, Germany). The crown was cemented with the self-adhesive cement seT PP, shade WO (SDI Limited, Bayswater Victoria, Australia).

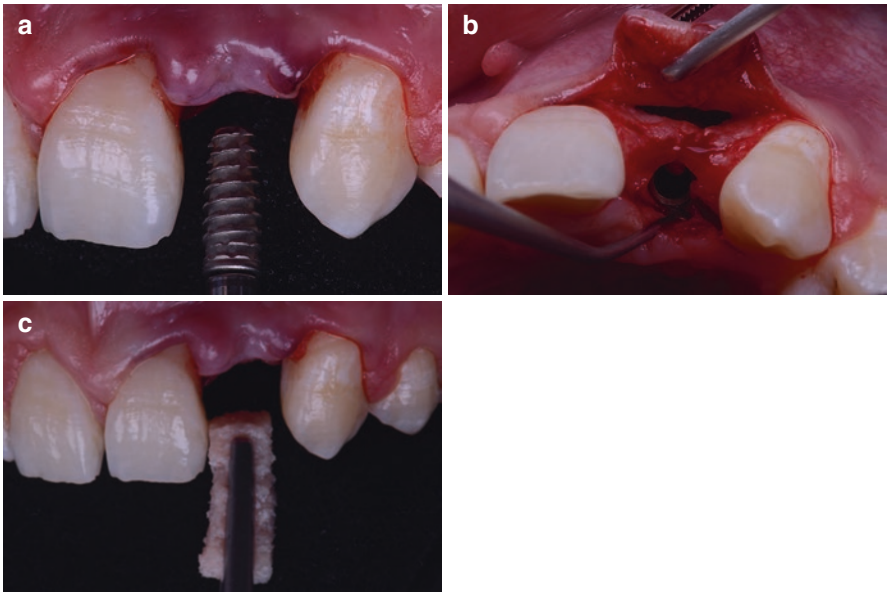


Fig. 17.6 (**a**) Implant placement. (**b**) Exact three-dimensional positioning of the implant. (**c**) An alloplastic bone graft was adapted to the buccal wall

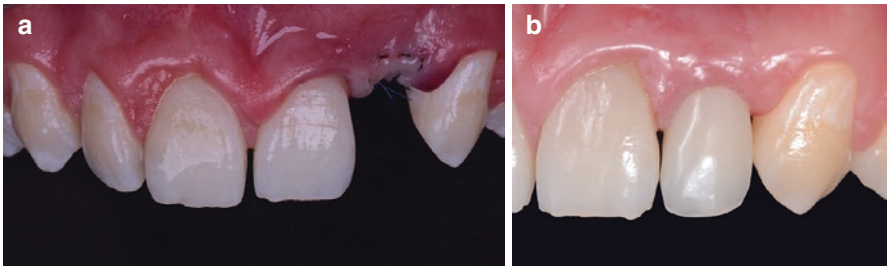


Fig. 17.7 (**a**) Frontal view after suturing and completion of the surgical step. (**b**) The CAD-CAM provisional crown

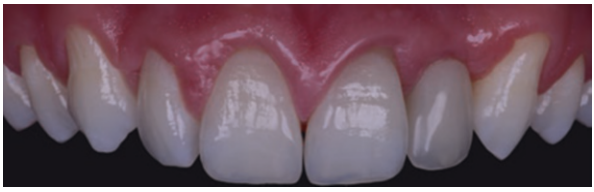


Fig. 17.8 After at-home bleaching and direct composite veneers

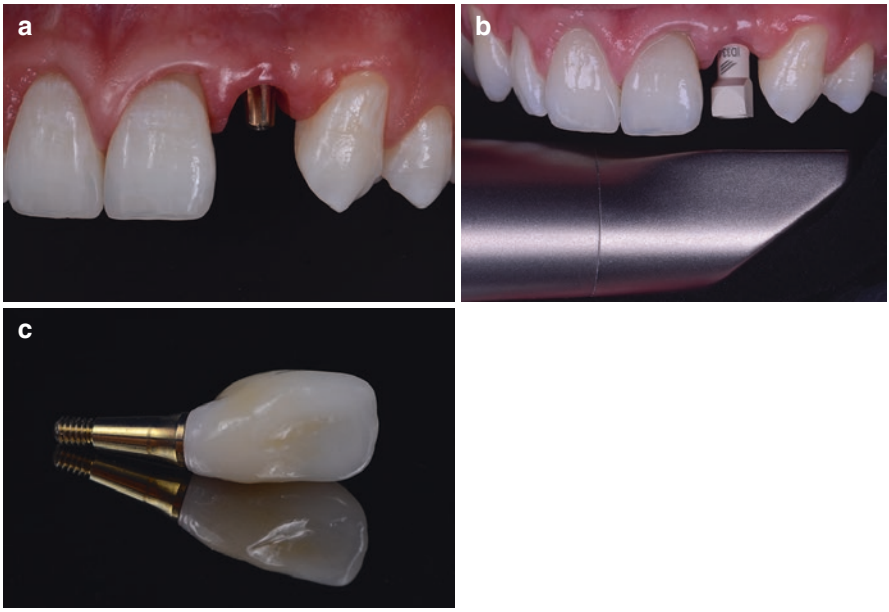


Fig. 17.9 (**a**) Single-body solid prosthetic abutment was selected and inserted. (**b**) Scanning body positioned on the prosthetic abutment, enabling intraoral scanning. (**c**) The final bilayered ceramic crown was manufactured using traditional 3Y-TZP veneered with feldspathic ceramic

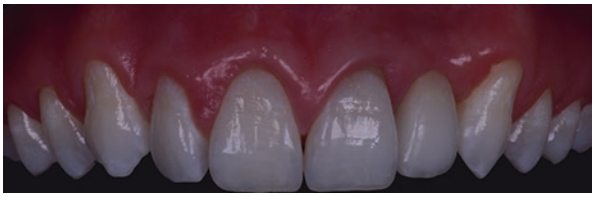


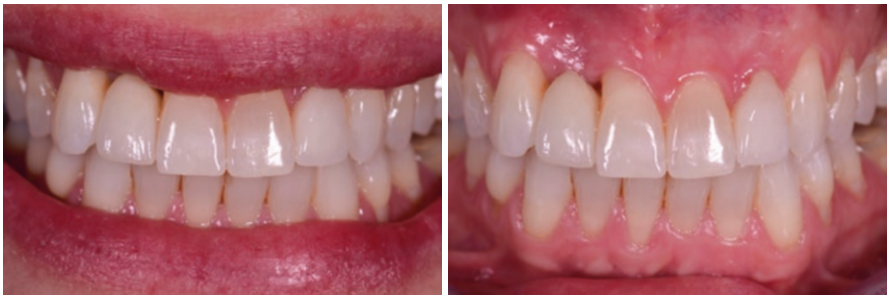
Fig. 17.10 Esthetic outcome with ceramic crown

17.2 At-Home Bleaching, Ceramic Veneers, and Crown with Artificial Gingiva

A patient sought the dental clinic because of the esthetic appearance of her smile. In addition to the dark space in the region of tooth #7 (FDI 1.2) and root exposure of tooth #8 (FDI 1.1), the patient was bothered by the darker aspect of #9 (FDI 2.1).

According to the patient's report she suffered an accident approximately 9 years back, which caused a root fracture of tooth #7 (FDI 1.2). Still according to the patient, tooth #7 (FDI 1.2) was extracted immediately and an implant was subsequently inserted in the same region. During the second phase of her treatment two ceramic crowns were made on teeth #7 (FDI 1.2) (implant) and #10 (FDI 2.2). The

patient also reported that she had undergone two surgical procedures ("gingival surgery", probably connective tissue graft), in an attempt to increase/recover the volume of the gingival contour in the implant region. The esthetic result of the region after the surgeries became even more compromised. As a result the patient decided that she did not want any further surgery in the same region of the mouth (Figs. 17.11, 17.12, 17.13, 17.14, and 17.15).



Figs. 17.11 Pre-treatment view showing the unsatisfactory esthetics from the absence of gingival tissue volume caused by bone loss in the region of the crown over the implant of tooth #7 (FDI 1.2). The color change of tooth #9 (FDI 2.1) also compromised the esthetics. Radiographically this tooth had a process of pulp calcification (calcific metamorphosis) resulting from the trauma

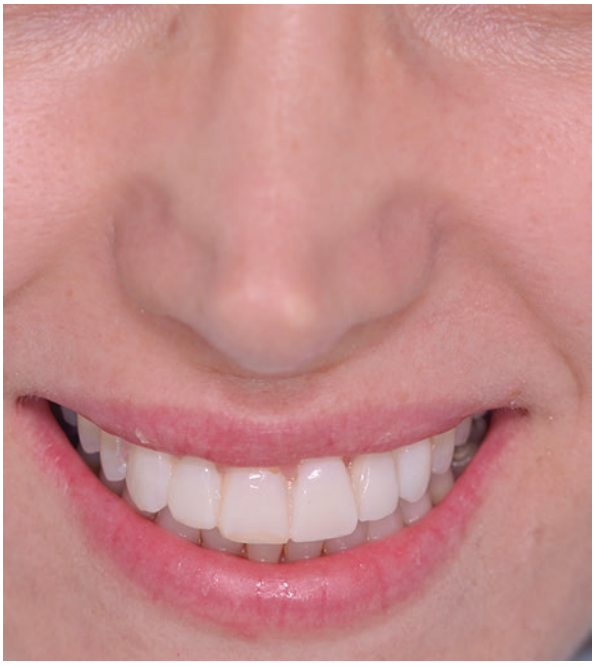


Fig. 17.12 Frontal view after completion of the bleaching treatment with 15% carbamide peroxide (at-home bleaching for 4 weeks). A mockup with bis-acryl resin was tested to define the morphology of the final ceramic restorations

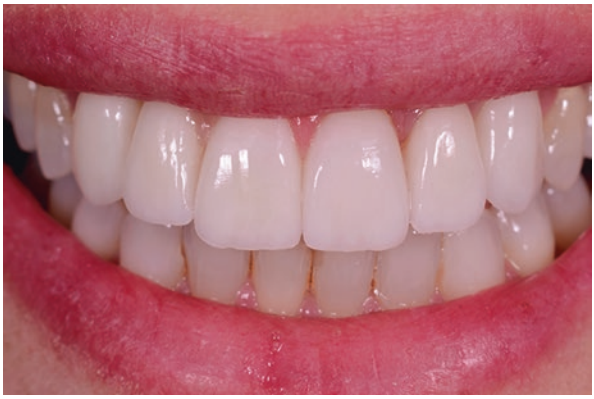
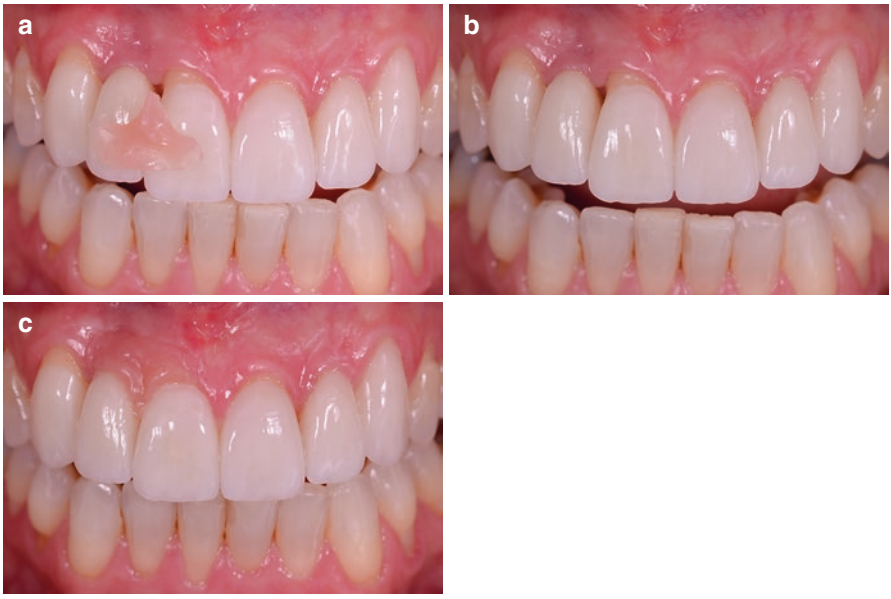


Fig. 17.13 Aspect after completion of the esthetic treatment with ceramic veneers on teeth #6 (FDI 1.3), #8 (FDI 1.1), #9 (FDI 2.1), #10 (FDI 2.2), and #11 (FDI 2.3). Tooth #7 (FDI 1.2) was restored with a lithium disilicate implant crown



Figs. 17.14 (**a**) Artificial gingiva. (**b**) Without the artificial gingiva. (**c**) Note the final contour and gingival volume after using artificial gingiva made of composite resin for the papilla reconstruction between teeth #7 (FDI 1.2) and #8 (FDI 1.1)

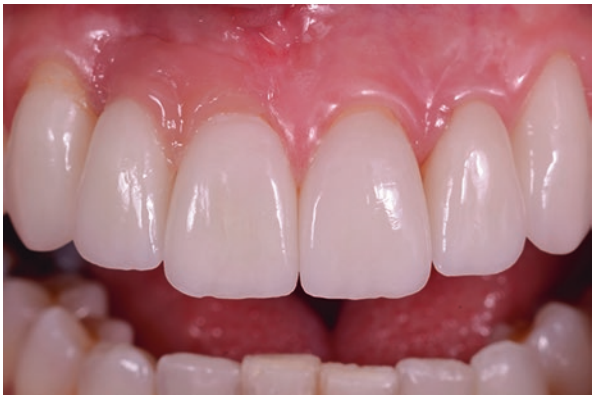


Fig. 17.15 Patient was extremely satisfied with the esthetic result

17.3 At-Home Bleaching and Ceramic Crown to Restore a Dark Incisor

A young patient was dissatisfied with the esthetic appearance of a ceramic crown that, according to the patient, had started to darken 2 years ago. Tooth #9 (FDI 2.1) had been endodontically treated and restored with a fiber post. For this reason it was decided not to perform any internal whitening treatment of this tooth. Instead, we prescribed at-home whitening of the two arches with 10% carbamide peroxide followed by a new ceramic crown on tooth #9 (FDI 2.1) (Figs. 17.16, 17.17, 17.18, 17.19, and 17.20).

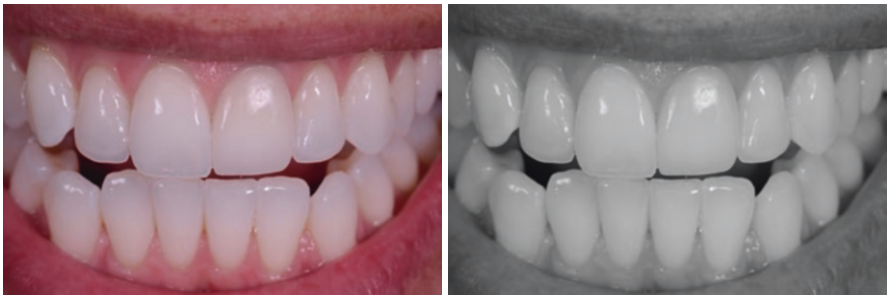


Fig. 17.16 Initial photographs depicting the unattractive appearance resulting from the grayish color (low value) of the crown of tooth #9 (FDI 2.1), which is more evident in a black and white photograph. Also note the inadequate length of the ceramic crown used to restore the same tooth

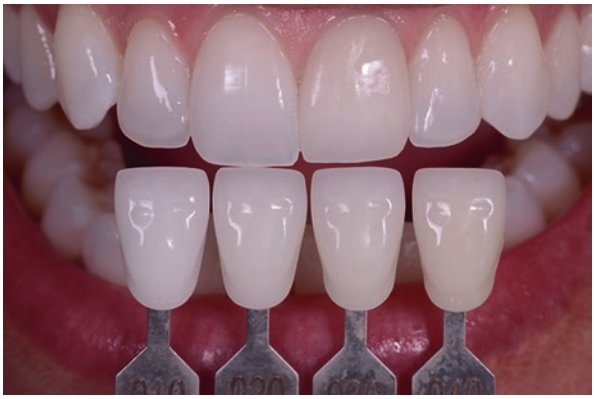


Fig. 17.17 Photograph taken with a shade guide to check and monitor the color of the teeth during the whitening treatment with 10% carbamide peroxide for 3 weeks

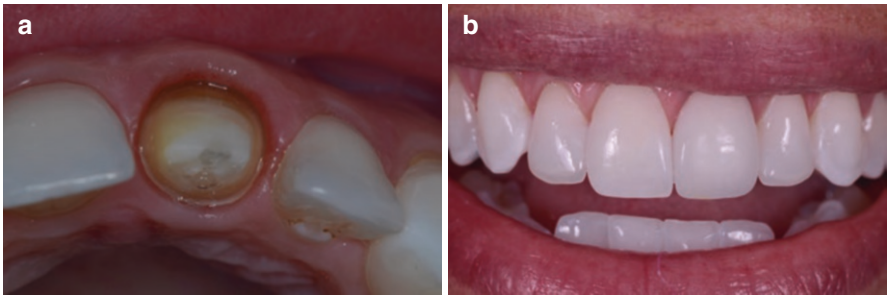


Fig. 17.18 (**a**) Incisal view after removal of the deficient ceramic crown 1 week after the completion of the bleaching treatment. (**b**) Frontal view after cementing a provisional crown made of bis-acryl resin

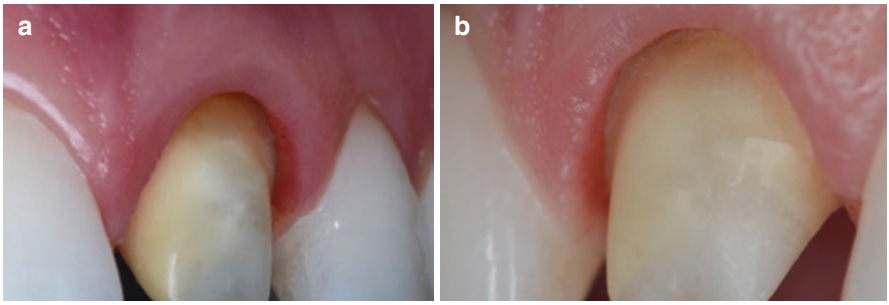


Fig. 17.19 (**a**) Photograph of the preparation and the healthy aspect of the gingival tissue 1 week after inserting the provisional crown. (**b**) Higher magnification of the preparation margin before taking the impression

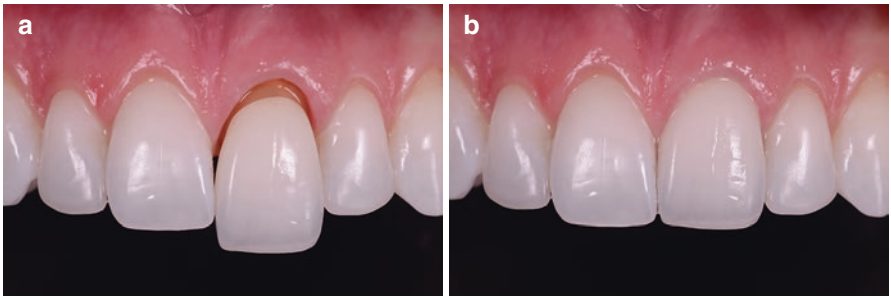


Fig. 17.20 (**a**) Try-in of the lithium disilicate crown (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein). (**b**) After cementation with Scotchbond Universal Adhesive and RelyX Ultimate (3 M Oral Care, St. Paul, MN, USA)

Acknowledgments *Rodrigo Barbosa Lima (implant surgery).
**Edson Araujo (direct composite restorations).
***Karina Nunes Pessoa (dental laboratory work).

Reference

Haywood VB, Al Farawati F (2019) Bleaching update and the future impact on prosthodontics. Br Dent J 226:753–760

Enamel Discolorations Not Amenable to Bleaching

18

Edson Araujo and Jorge Perdigão

Abstract

Although dental professionals have an armamentarium of techniques for disguising or removing tooth discolorations, these techniques are not always successful. This chapter is focused on restorative options for discolored vital and nonvital teeth that do not respond to bleaching.

18.1 Teeth with Dental Fluorosis Treated with Porcelain Veneers

The major complaint of this 19-year-old patient was related to the color of the front teeth (Fig. 18.1). The patient described major social difficulties at school because of the "yellow smile." This patient had lived in a rural area where other people in the same community had discolored teeth, including some of the patient's family members.

There were no medical conditions and no family history related to the appearance of the teeth. The clinical exam revealed that the periodontal condition was excellent. Radiographically there were no structural areas of concern in the periodontal and periapical areas. The diagnosis for this clinical case was dental fluorosis. This patient's fluorosis level would fall into a TSIF score of 4 (Horowitz et al. 1984) and a TF index score of 4 (Thylstrup and Fejerskov 1978). The treatment plan

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J. Perdigão (ed.), *Tooth Whitening*, https://doi.org/10.1007/978-3-031-38244-4_18

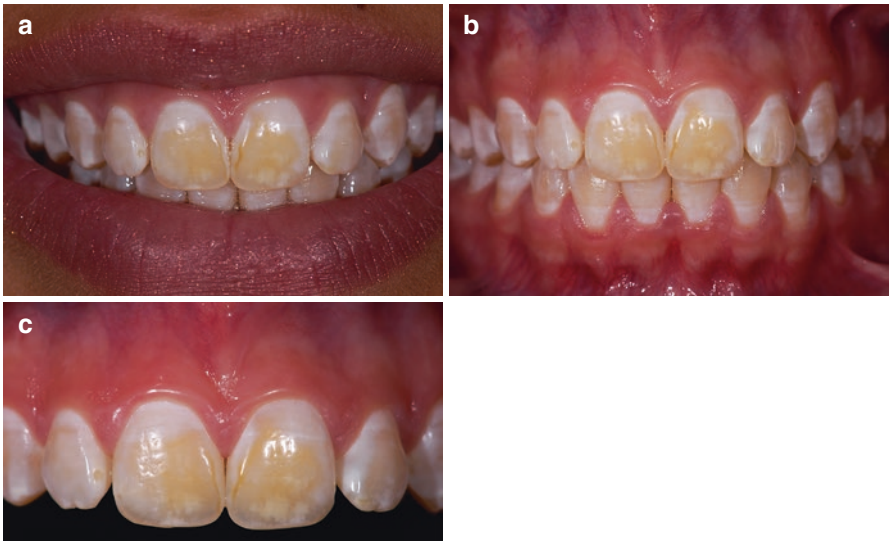

Fig. 18.1 (**a**) Non-retracted frontal view showing the wide yellowish discoloration on teeth #8 (FDI 1.1) and #9 (FDI 2.1) and white spot areas in other teeth. Some teeth display single pitted enamel areas. (**b**) Retracted view. The lower incisors also have yellowish discolorations along the perikymata. (**c**) Close-up view of the maxillary incisors

proposed to the patient was at-home bleaching with 10% carbamide peroxide gel in a custom-fitted tray for 1 month and possibly every month thereafter up to 5–6 months depending on the outcome after the first month. If at-home bleaching did not result in "whiter" teeth, we would then try enamel microabrasion or a more invasive restorative procedure, such as direct or indirect veneers. Patient was informed that microabrasion is usually less conservative than at-home whitening. Patient accepted this initial treatment plan.

Patient returned to the dental office after 5 weeks. No visible changes had occurred with the color of the teeth. Patient's compliance might have been the reason for the apparently unsuccessful whitening regimen. The patient mentioned that she forgot to wear the trays for a few days. At this point we asked the patient if she wanted to start the enamel microabrasion procedure, which the patient declined and asked for a "more permanent solution."

After presenting the restorative treatment options to the patient, which included direct resin-based composite veneers or porcelain veneers, the patient returned 2 weeks later to start the clinical procedure for eight thin porcelain veneers (Figs. 18.2, 18.3, 18.4, and 18.5).

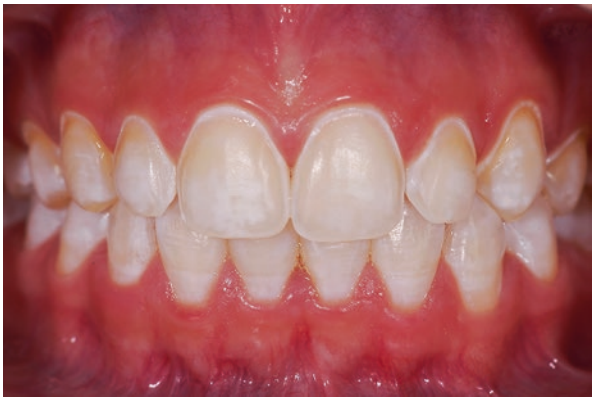

Fig. 18.2 Preparation of the maxillary teeth for porcelain veneers. Patient was not anesthetized because the preparation was limited to enamel

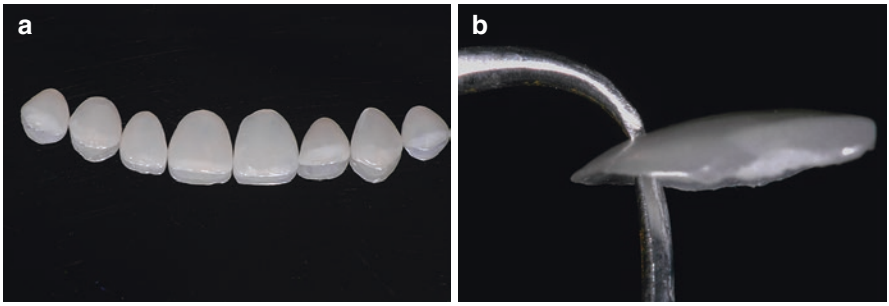

Fig. 18.3 (**a**) Porcelain veneers were fabricated with lithium disilicate (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein). (**b**) The thickness of the veneers ranged from 0.2 mm to 0.3 mm

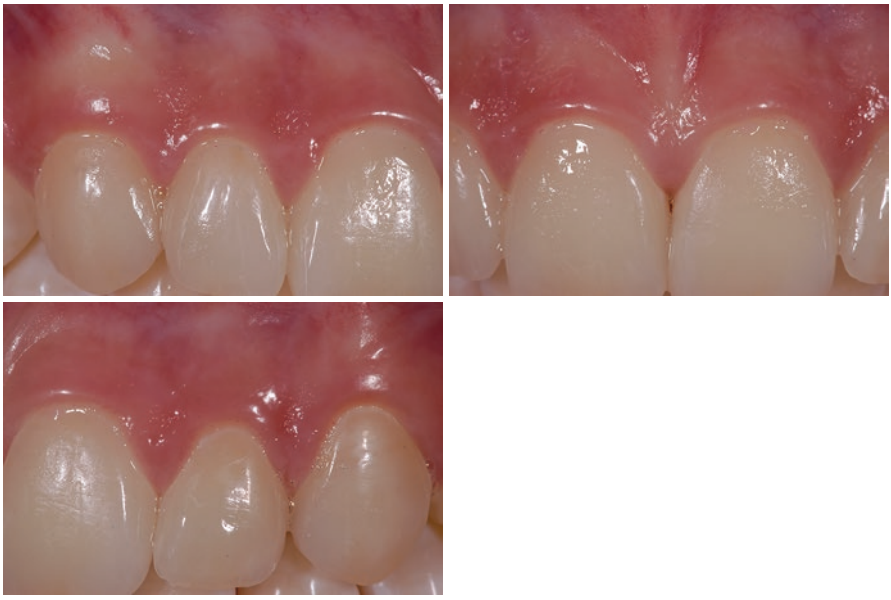

Fig. 18.4 The veneers were cemented with a two-step etch-and rinse adhesive system (Adper Single Bond Plus, 3M Oral Care, St. Paul, MN, USA) and a light-cured resin-based luting composite material (RelyX Veneer, 3M Oral Care). One week after the luting procedure, the integration of the porcelain restorations with the gingival tissue was excellent

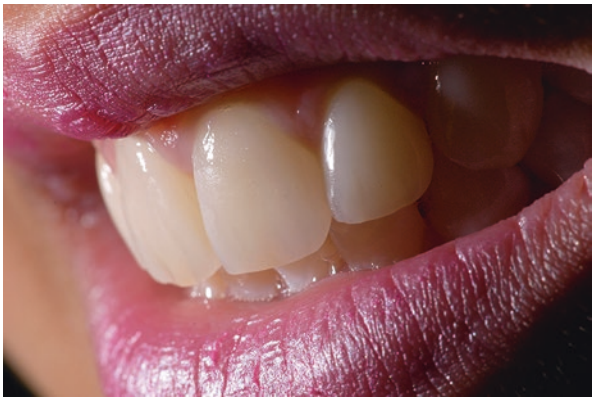

Fig. 18.5 The natural look of the patient's smile 1 week later

18.2 Teeth with Dental Fluorosis Restored with Porcelain Crowns After Esthetic Recontouring of the Gingival Tissue

Excessive fluoride intake may result in dental fluorosis, characterized by opaque white areas or discolorations ranging from yellow to dark brown (Horowitz et al. 1984). In more severe cases (Chap. 6), the enamel surface becomes pitted with porosities. Bond strengths to fluorotic enamel are much lower with self-etch adhesives compared to those obtained with etch-and-rinse adhesives (Ermis et al. 2007). A two-step etch-and-rinse adhesive results in statistically similar enamel bond strengths between fluorotic enamel and normal enamel (Ermis et al. 2007).

The clinical case depicted in Fig. 18.6 is that of a 20-year-old patient who decided to seek dental treatment because of the appearance of the teeth. This patient had lived in the same rural area as the patient in the previous clinical case. According to the information given to the patient's mother by the former dentist, the drinking water contained excessive fluoride. Other children in the same community had discolored white or brown teeth, according to the mother's recollection. The diagnosis for this clinical case was dental fluorosis.

Out of the six maxillary anterior teeth, only tooth #8 (FDI 1.1) would fall into TSIF score 6, as per Horowitz et al. (1984), and TF index score 5, as per Thylstrup and Fejerskov (1978). The other five maxillary anterior teeth would fall into TSIF score 7 (Horowitz et al. 1984) and TF index score 6 (Thylstrup and Fejerskov 1978).

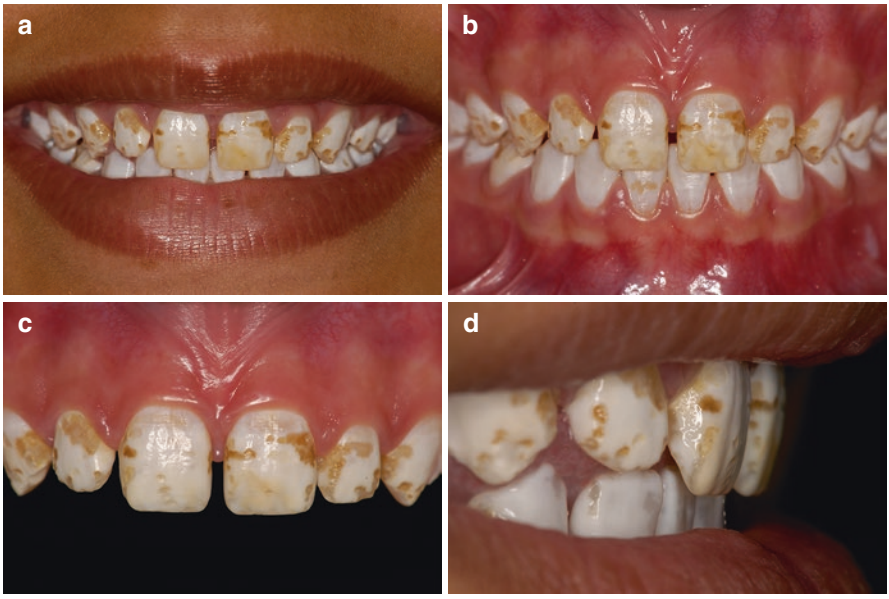

Fig. 18.6 (**a**) Non-retracted frontal view of patient's anterior teeth. (**b**) Retracted view showing enamel fluorosis in all teeth. (**c**) Close-up view of the maxillary incisors. (**d**) Lateral close-up view of the anterior teeth

Clinical and radiographic exams did not disclose any problem with soft tissues, pulp vitality, and periodontal health. Esthetically, the shape of the anterior teeth was not harmonious. The lateral incisors were too short, while the central incisors were square-shaped. A waxed-up model was prepared with longer clinical crowns and a more pleasant proportion. This model was used to explain to the patient how a change in the size of the clinical crowns might enhance the smile.

The following treatment plan was agreed with the patient:

1. Direct resin-based composite veneers to mask the discolorations as an immediate solution and to improve the patient's self-confidence (Fig. 18.7). The patient was informed that the aspect of the smile would improve considerably although the patient would still notice a few areas of discoloration.
2. A second phase of the treatment would include a gingivoplasty procedure to reshape and recontour the tissue and lengthen the clinical crowns (Fig. 18.8). After soft tissue healing, minimally invasive preparations for porcelain crowns would be carried out followed by thin porcelain restorations bonded to enamel to restore function and esthetics (Figs. 18.9 and 18.10).

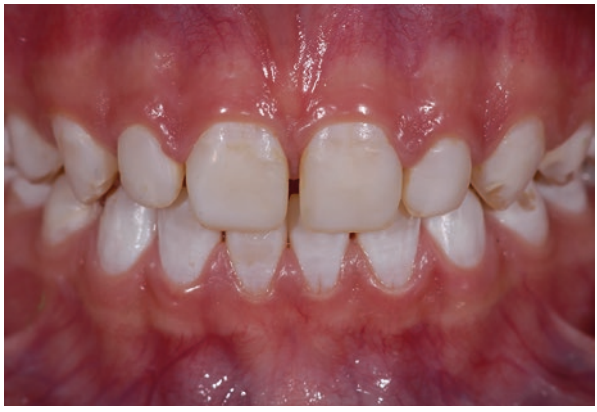

Fig. 18.7 Direct resin-based composite restorations were inserted using a two-step etch-and-rinse adhesive after slightly roughening the enamel

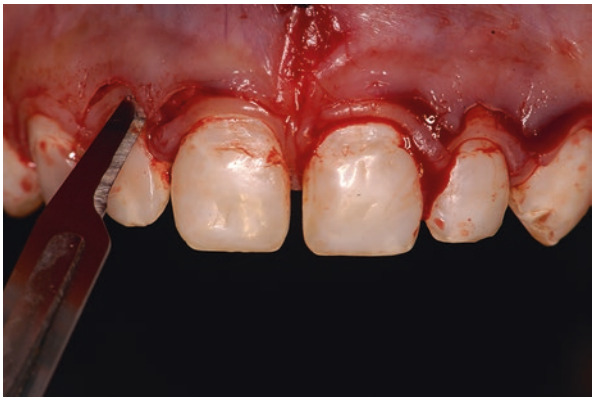

Fig. 18.8 Gingivoplasty to recontour the gingival tissue

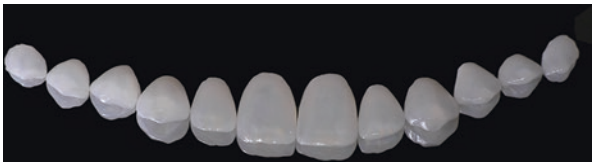

Fig. 18.9 IPS e.max Press (Ivoclar Vivadent) lithium disilicate restorations as received from the dental laboratory

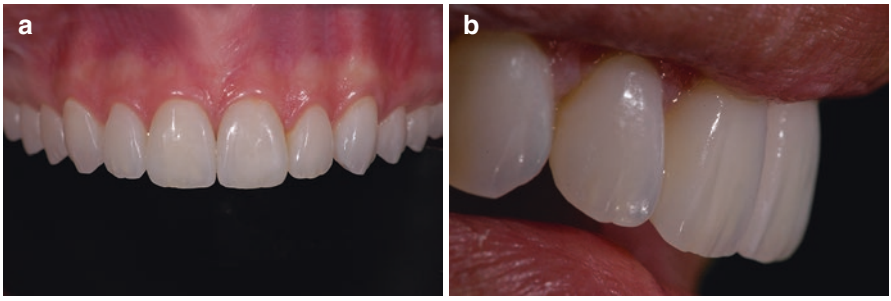

Fig. 18.10 (**a**) Postoperative view immediately after bonding the ceramic restorations with a two-step etch-and-rinse adhesive (Adper Single Bond Plus, 3M Oral Care) and a dual-cured resin-based luting composite material (RelyX ARC, 3M Oral Care). (**b**) Patient's smile two days after the restorations were bonded

18.3 Restorative Solution for a Case of Unsuccessful Internal Bleaching

Intracoronal bleaching of root-filled teeth has a fairly good prognosis for discolorations caused by necrotic pulp tissue or blood components, with a short-term success rate of 50%– 90%, as described in Chap. 8. Unfortunately, the long-term success rate is considerably lower as some color regression may occur after the initial bleaching effect.

This 35-year-old patient was concerned about the discoloration of the right maxillary central incisor (Fig. 18.11). According to the patient, this tooth had been endodontically treated 6 years ago and immediately became darker. Another dentist performed three intracoronal bleaching sessions 3 years after the root canal treatment, followed by two sessions of external in-office whitening. In spite of a slight improvement in the tooth color, the patient never felt that the tooth was esthetically acceptable.

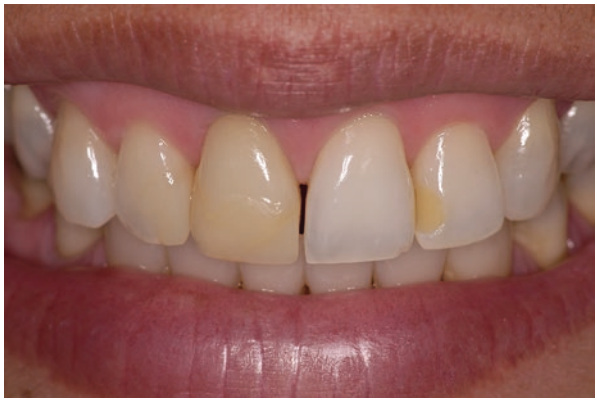

Fig. 18.11 Preoperative view showing the discoloration of tooth #8 (FDI 1.1)

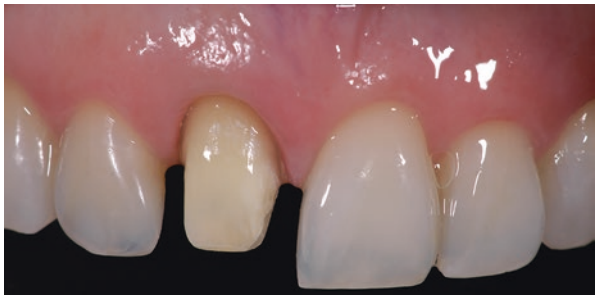

Fig. 18.12 After replacement of resin-based composite restorations and preparation of tooth # 8 (FDI 1.1) for a porcelain crown

The medical history was not contributory. Radiographically tooth #8 (FDI 1.1) had no evidence of root resorption or periapical pathology. The radiographic evaluation of the root canal treatment did not raise any questions. The clinical exam revealed a few areas of incipient caries lesions in the posterior area, besides defective resin-based composite restorations in the anterior segment. The treatment plan proposed to solve the compromised esthetics included replacement of the resin-based composite restorations on teeth #7 (FDI 1.2), #9 (FDI 2.1), and #10 (FDI 2.2), followed by a bonded porcelain crown to correct the discoloration of tooth #8 (FDI 1.1). Figure 18.12 shows tooth #8 (FDI 1.1) after preparation for a full-coverage ceramic restoration and new resin-based composite restorations on the other maxillary incisors, and Fig. 18.13 depicts the shade match using the Vita Classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) to compare with tooth #9 (FDI 2.1). The restoration was fabricated with lithium disilicate (IPS e.max Press, Ivoclar Vivadent) and cemented with Adper Single Bond Plus and RelyX ARC (3M Oral Care) (Figs. 18.14, 18.15, and 18.16).

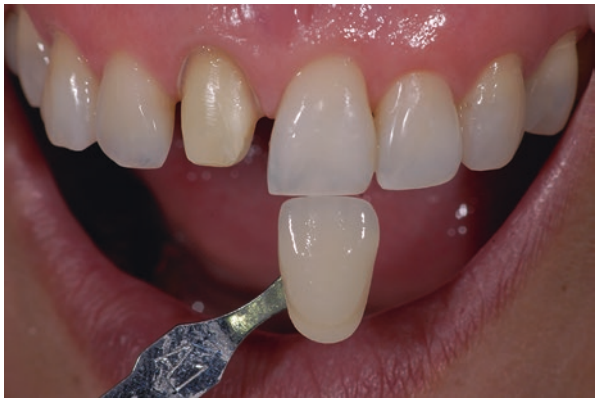

Fig. 18.13 Shade matching to the Vita Classical A1–D4 shade guide

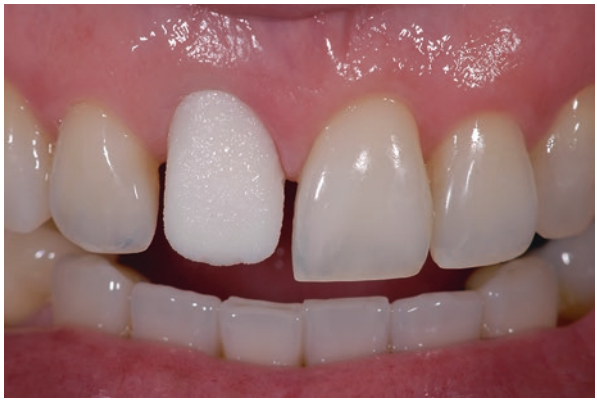

Fig. 18.14 High-opacity lithium disilicate coping try-in (IPS e.max Press HO, Ivoclar Vivadent)

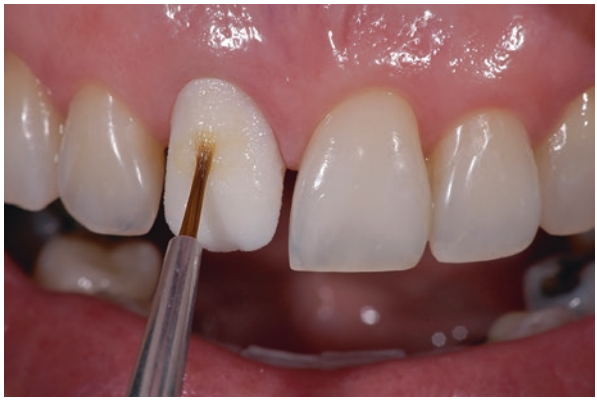

Fig. 18.15 Characterization of the opaque ceramic coping

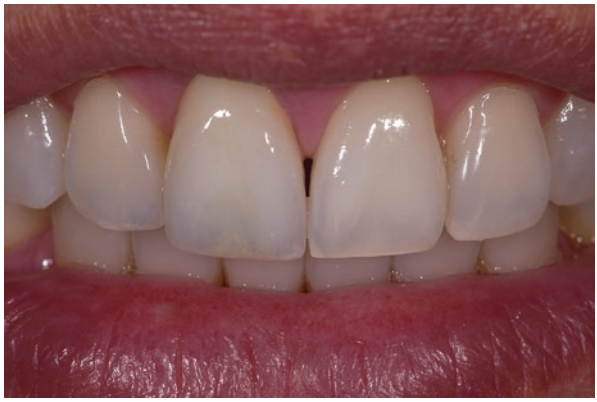

Fig. 18.16 Frontal view after adhesive cementation of the lithium disilicate ceramic crown

18.4 Enamel Idiopathic Hypomineralization Treated with Direct Resin-Based Composite

At-home bleaching may highlight enamel hypomineralized areas and make them more pronounced in case they are located deep in the enamel, as discussed in Chap. 6. The extraoral photograph shown in Fig. 18.17a is that of a 19-year-old patient who had bleached the teeth for 3 weeks with 10% carbamide peroxide in a custom-fitted tray. All the patients' anterior teeth were vital without any clinical or radiographic signs of pathology, except for the enamel hypomineralized area on tooth #10 (FDI 2.2).

According to the patient's description, the white enamel area of tooth #10 (FDI 2.2) became wider and more opaque with the whitening treatment. Clinically, the white opaque enamel area exhibited a concavity in the central area of the lesion, denoting loss of enamel (Fig. 18.17b). Transillumination confirmed that the center of the lesion had a thinner area of tooth structure compared to the periphery (Fig. 18.18). The intense opacity of the tooth structure surrounding the more translucent zone suggested that the defect was deep into the tooth, therefore not amenable to enamel microabrasion or to resin infiltration.

The treatment plan was removal of the hypomineralized area (Fig. 18.19), etching with 35% phosphoric acid for 15 s, and restoring the area with a two-step etch-and-rinse adhesive (Adper Single Bond Plus, 3M Oral Care) followed by a resin-based composite resin (Filtek Supreme Ultra, 3M Oral Care). After inserting and light curing the resin-based composite, the restoration was finished with Sof-Lex XT discs (3M Oral Care) (Fig. 18.20a) followed by characterization of the secondary anatomy (Fig. 18.20b) with a composite finishing bur. A felt disk (Diamond Flex, FGM Dental Group, Fort Lauderdale, FL, USA) with a fine diamond paste (Diamond Excel, FGM Dental Group) was used for the final polishing step (Fig. 18.20c). Fig. 18.21 is a close-up photograph of the final aspect of restored tooth #10 (FDI 2.2) showing an optimal esthetic integration with the other anterior teeth. Fig. 18.22 portrays the patient's new smile.

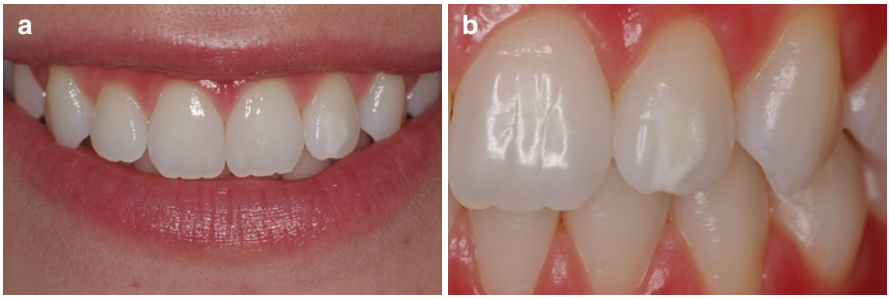

Fig. 18.17 (**a**) Smile of a 19-year-old patient who had recently bleached her teeth with 10% carbamide peroxide in a custom-fitted tray for 3 weeks. (**b**) An enamel hypomineralized area on tooth #10 (FDI 2.2) with a concavity in the central area of the lesion denoting loss of enamel

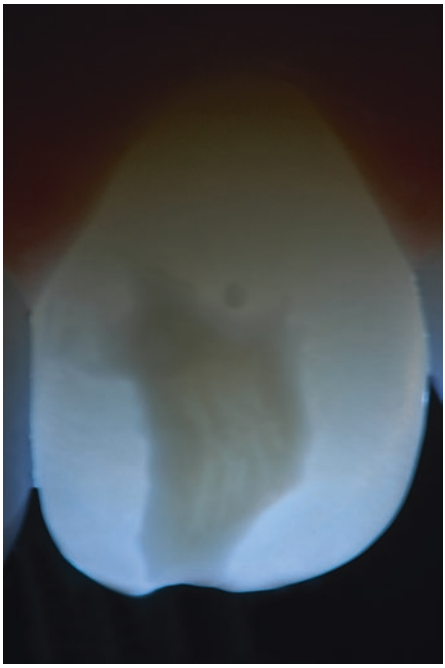

Fig. 18.18 Transillumination confirmed a thinner area of tooth structure (concavity) at the center of the hypomineralized area

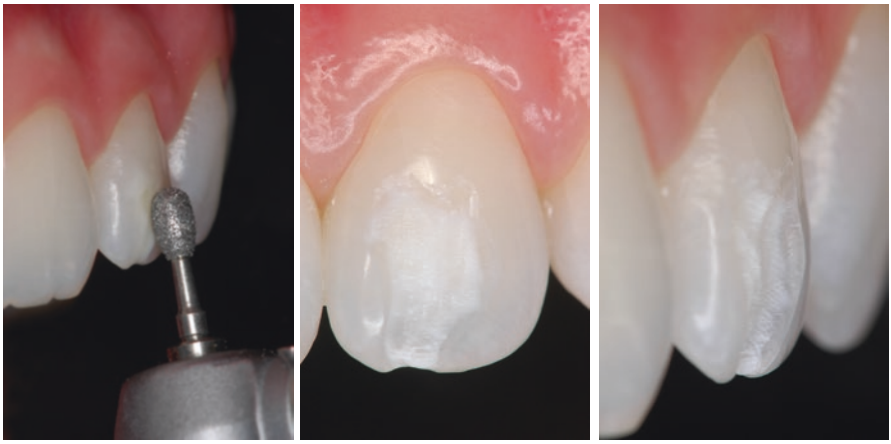

Fig. 18.19 The decalcified porous enamel was removed with a diamond bur

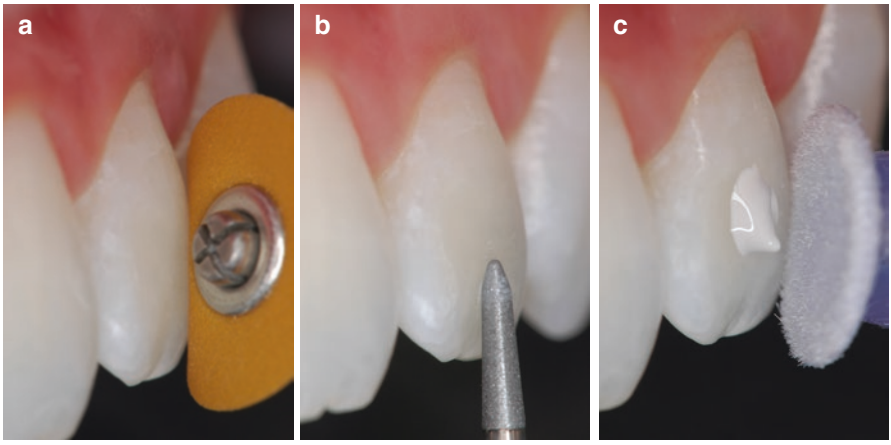

Fig. 18.20 After etching with 35% phosphoric acid for 15 sec, a two-step etch-and-rinse adhesive was applied, gently air-dried, and light cured, followed by a nanofilled resin-based composite. (**a**) Finishing with aluminum oxide disks; (**b**) Placing secondary anatomy with a fine diamond finishing bur; (**c**) The final polishing step was carried out with a felt disk impregnated with a fine diamond paste

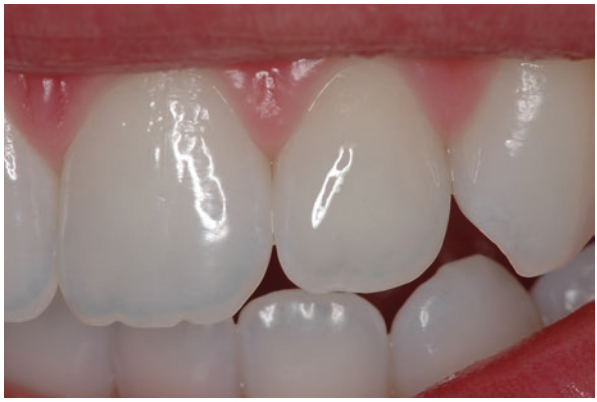

Fig. 18.21 Close-up photograph of tooth #10 (FDI 2.2) after polishing the restoration

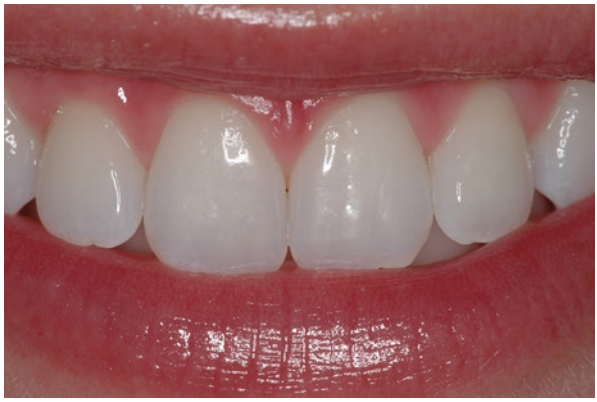

Fig. 18.22 Patient was extremely happy with the treatment outcome

References

Ermis RB, De Munck J, Cardoso MV, Coutinho E, Van Landuyt KL, Poitevin A, Lambrechts P, Van Meerbeek B (2007) Bonding to ground versus unground enamel in fluorosed teeth. Dent Mater 23:1250–1255

Horowitz HS, Driscoll WS, Meyers RJ, Heifetz SB, Kingman A (1984) A new method for assessing the prevalence of dental fluorosis - the tooth surface index of fluorosis. J Am Dent Assoc 109:37–41

Thylstrup A, Fejerskov O (1978) Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes. Community Dent Oral Epidemiol 6:315–328