Complications from the Use of Peroxides

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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

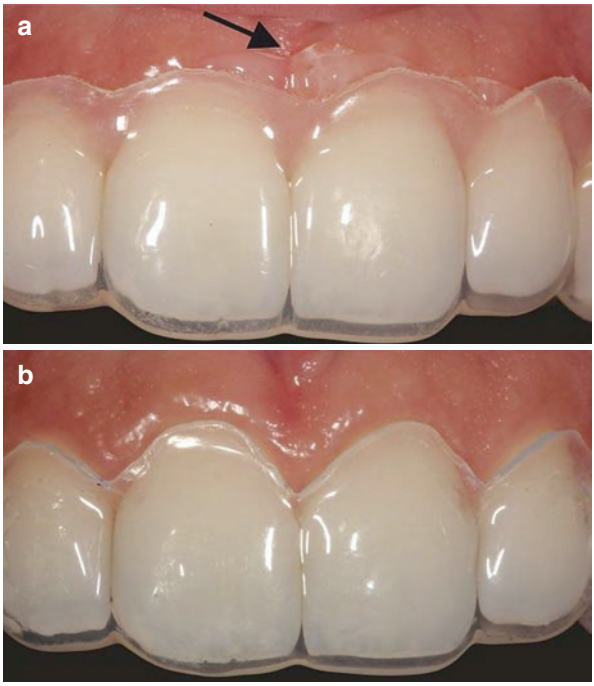

Fig. 4.1 (**a**) Traditional tray showing the possibility of direct contact of the bleaching gel with soft tissue. (**b**) The scalloped tray that keeps the bleaching gel in contact exclusively with the enamel tissue

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

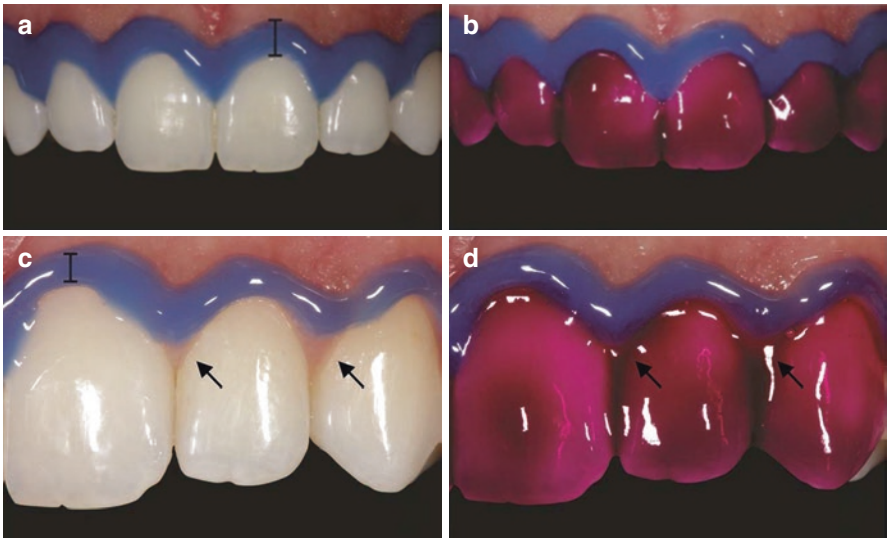

Fig. 4.2 (**a**) Correct use of the gingival barrier, carefully positioned around the cervical region covering the interdental papilla and a considerable portion of the marginal gingiva. (**b**) Correct application of bleaching gel minimizing the possibility of any undesirable incident with the product. (**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

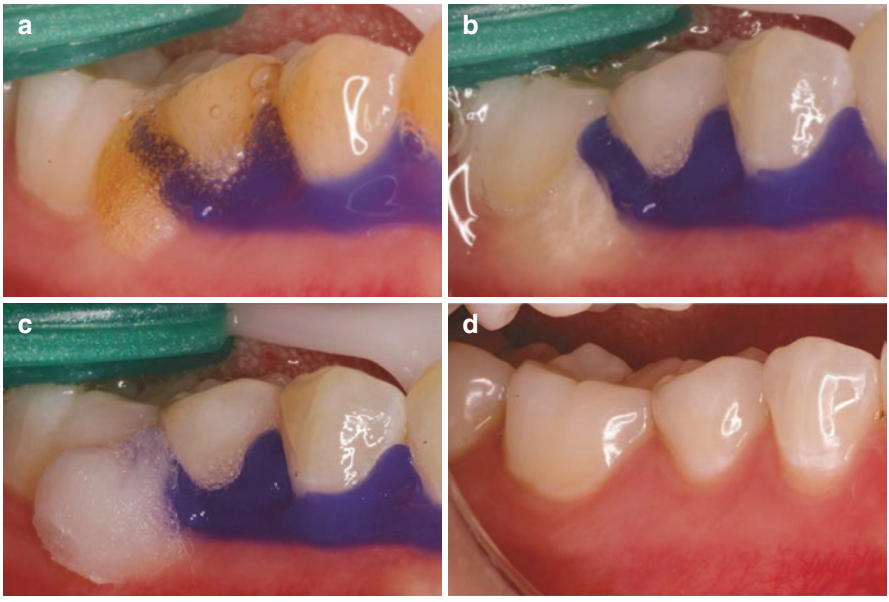

Fig. 4.3 (**a**) The bleaching gel flowing to the area not protected by the gingival barrier. (**b**) Clinical characteristic of the gingival tissue immediately after contact with the bleaching gel. (**c**) Application of a neutralizing agent. (**d**) Clinical aspect of the gingival tissue 7 days after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

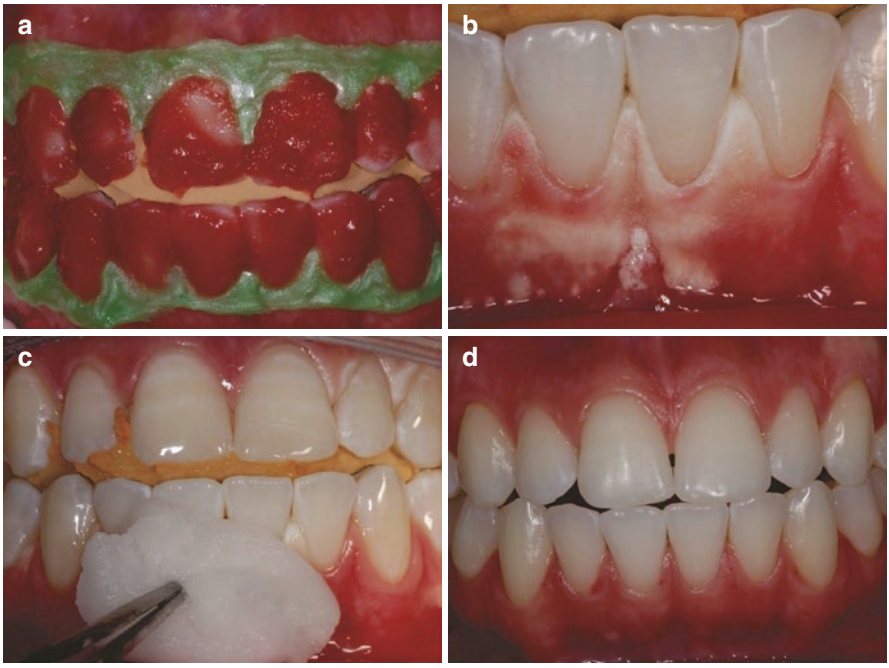

Fig. 4.4 (**a**) Lower incisors submitted to in-office bleaching. (**b**) The barrier may have been applied in an excessively humid operative field, or the gel may have kept in the mouth for too long which could have caused alterations in the thixotropic characteristics of the gel and subsequent seepage 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

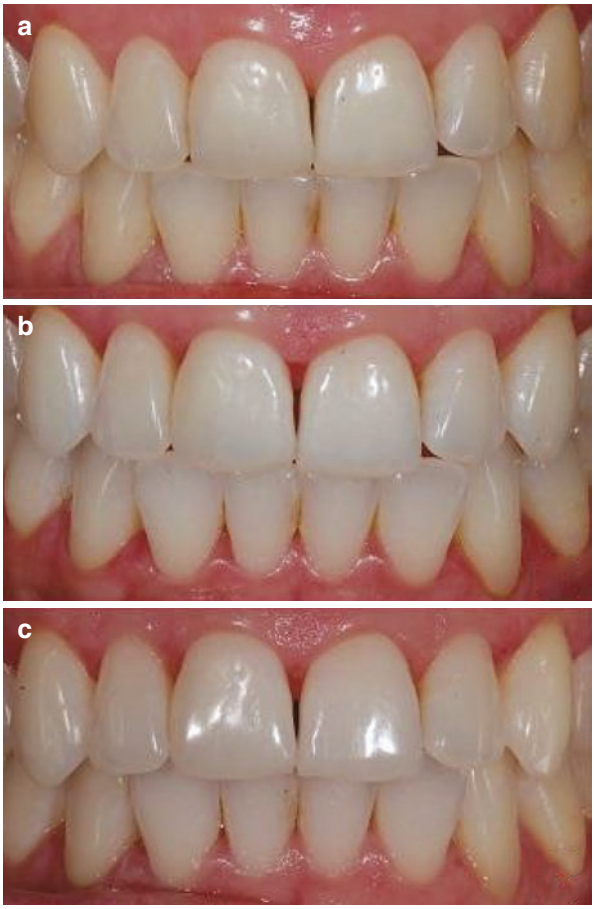

Fig. 4.5 Effect of the bleaching treatment on the gingival papilla region after the "jump-start" technique (association of at-home and in-office technique). We considered the possibility of allergic reaction to components of the bleaching product, since there was no compression of the tray in the papillae 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

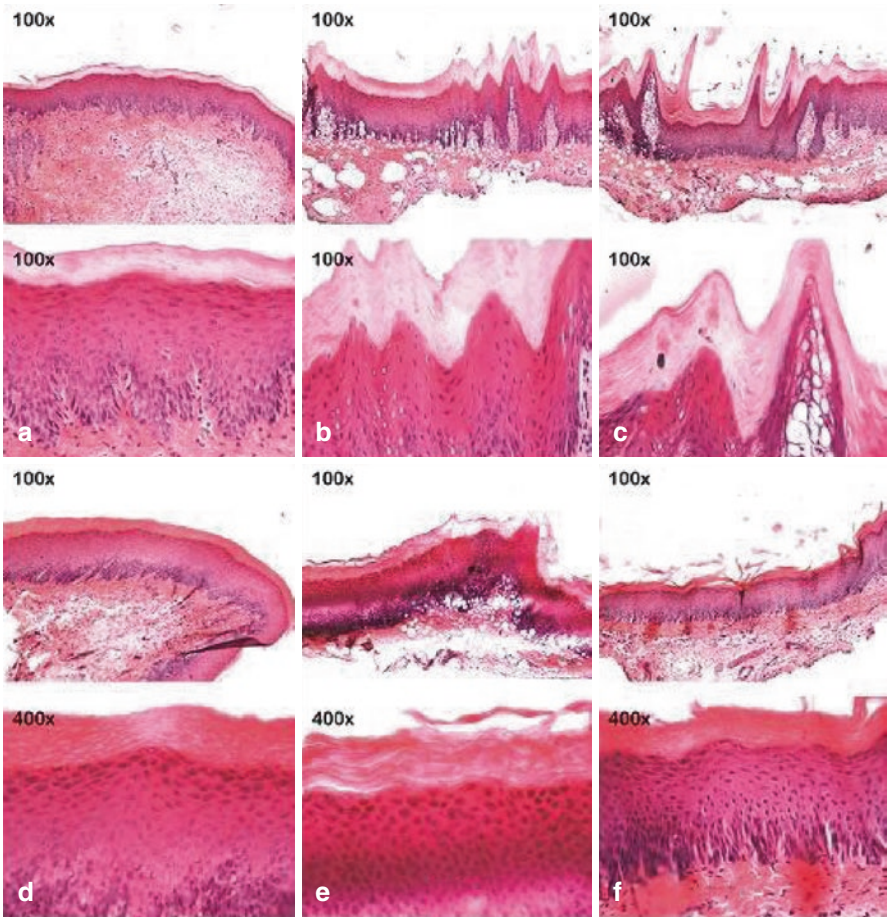

Fig. 4.6 (**a** and **d**) Bleaching gels are applied to the buccal mucosa of rats for 30 min followed by treatment or no treatment of the injured tissue with a neutralizing agent (sodium bicarbonate). The mucosa exposed to 10% CP gel does not show any notable change in the epithelium and underlying 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).

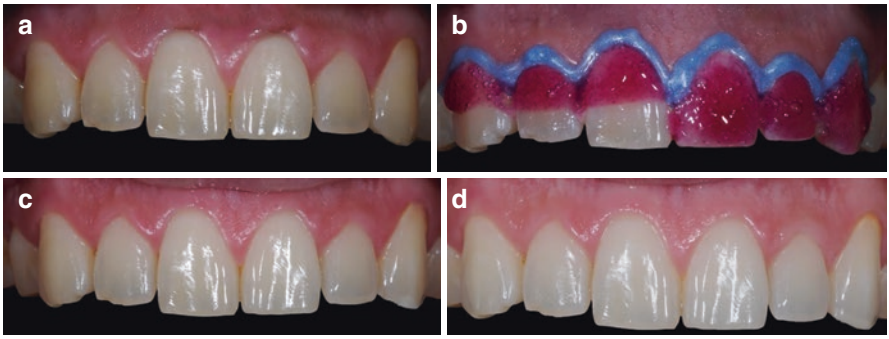

Fig. 4.7 (**a**) Treatment performed with application of bleaching gel in the cervical region vs. on the entire buccal surface. The baseline color of incisors and canines was VITA A3. (**b**) Different application protocols for the whitening gel. (**c**) Clinical aspect after the first session. (**d**)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

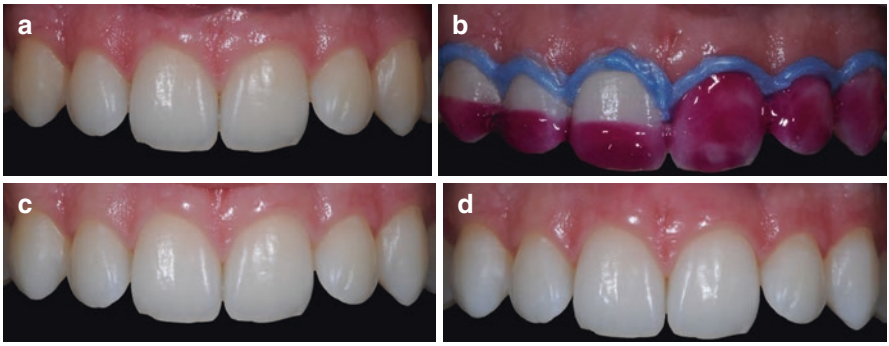

Fig. 4.8 (**a**) Application of bleaching gel on the incisal region vs. on the entire buccal surface. Baseline color was VITA A2. (**b**) Different application protocols for the whitening gel. (**c**) Clinical aspect after the first session. (**d**) Clinical aspect after three sessions. The color changes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

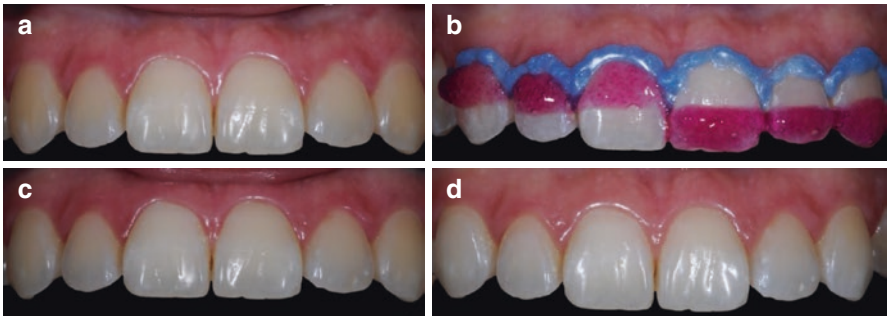

Fig. 4.9 (**a**) Application of bleaching gel on the cervical region vs. on the incisal region. Baseline color was VITA A2. (**b**) Different application protocols for the whitening gel. (**c**) Clinical aspect after the first session. (**d**) Final result. The color changes were homogeneous regardless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

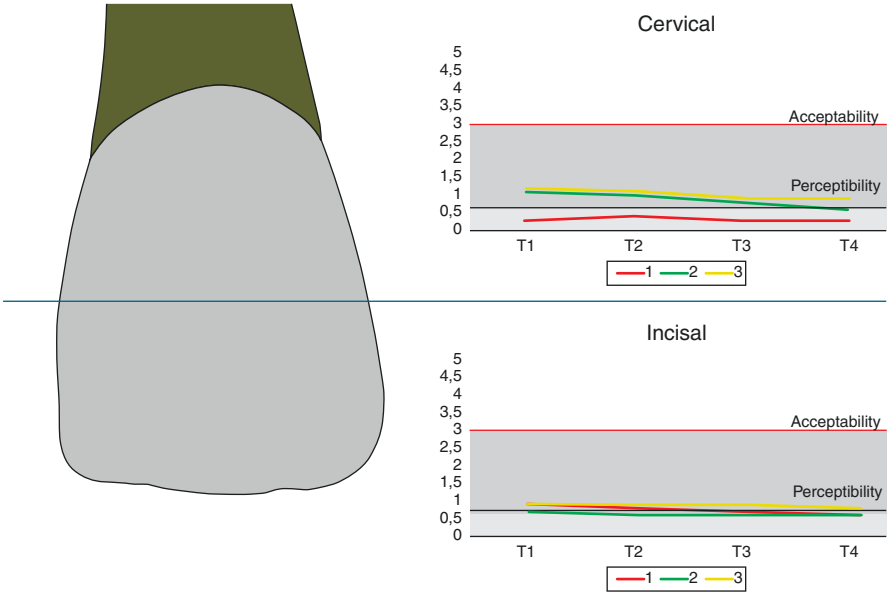

Fig. 4.10 Each line represents the difference in the ΔE values obtained for each hemiarch. Comparison of the perceptibility and acceptability limits with the ΔE values obtained in the cervical and incisal regions between the hemiarches (red line, application on the entire vestibular face vs. on the cervical (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

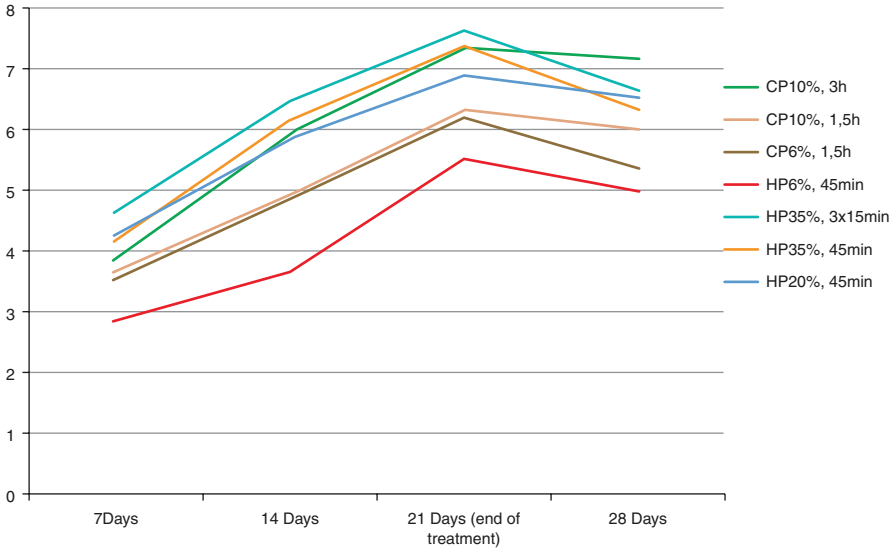

Fig. 4.11 Color change (Delta E), according to bleaching dosage employed and treatment time

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

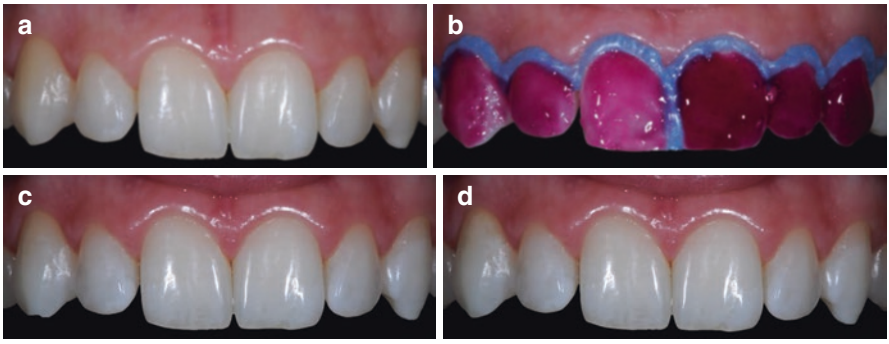

Fig. 4.12 Treatment performed with application of 35% H_2O_2 bleaching gel in a volume of 0.025 mL vs. 0.05 mL. (**a**) Initial appearance of maxillary incisors and canines with shade VITA A2. (**b**) Application of the bleaching gel. (**c**) Clinical aspect after the first session. (**d**) Clinical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

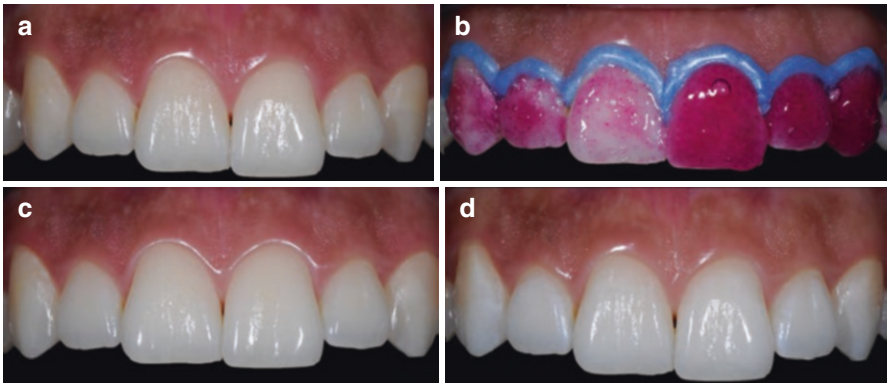

Fig. 4.13 Treatment performed with application of 35% H_2O_2 bleaching gel in a volume of 0.025 mL vs. 0.10 mL. (**a**) Initial appearance of maxillary incisors and canines with shade VITA A3. (**b**) Application of the bleaching gel. (**c**) Clinical aspect after the first session. (**d**) Clinical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

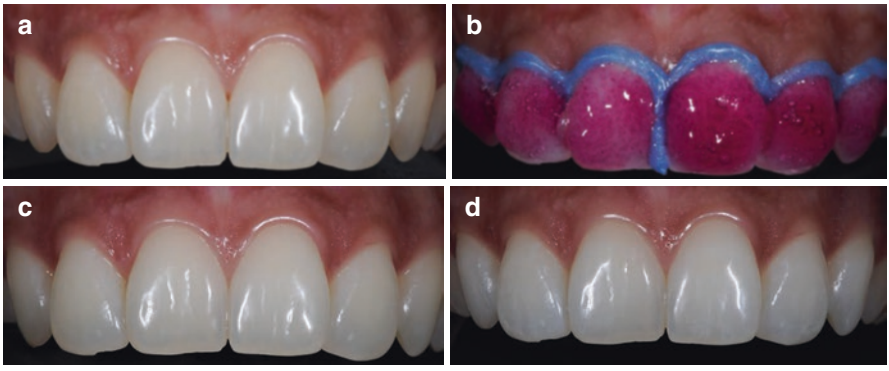

Fig. 4.14 Treatment performed with application of 35% H_2O_2 bleaching gel in a volume of 0.050 mL vs. 0.10 mL. (**a**) Initial appearance of maxillary incisors and canines with shade VITA A2. (**b**) Application of the bleaching gel. (**c**) Clinical aspect after the first session. (**d**) Clinical 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).

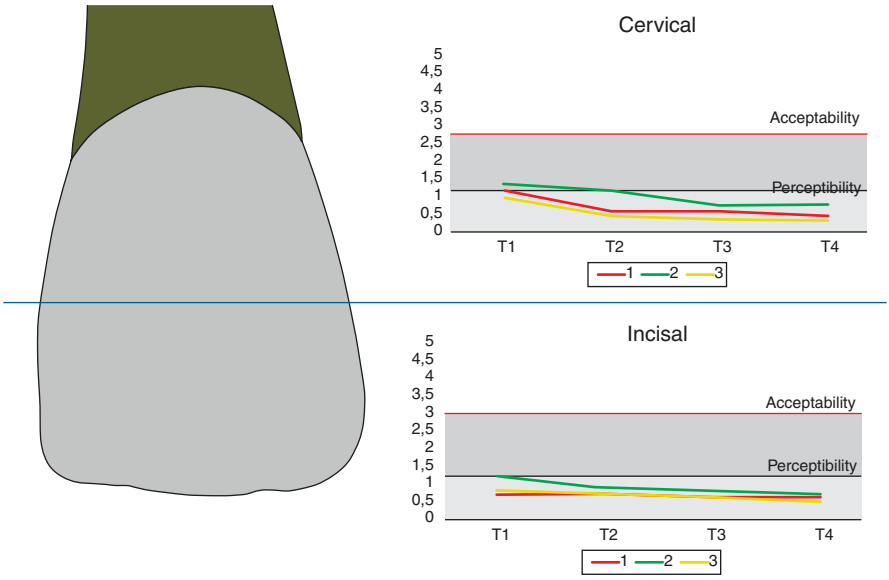

Fig. 4.15 Comparison of the perceptibility and acceptability limits with the ΔE values obtained in the cervical and incisal region between the hemiarches (red line, application of 0.025 mL of gel vs. application of 0.05 mL (Fig. 4.12); green line, application of 0.025 ml vs. application of 0.10 ml (Fig.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

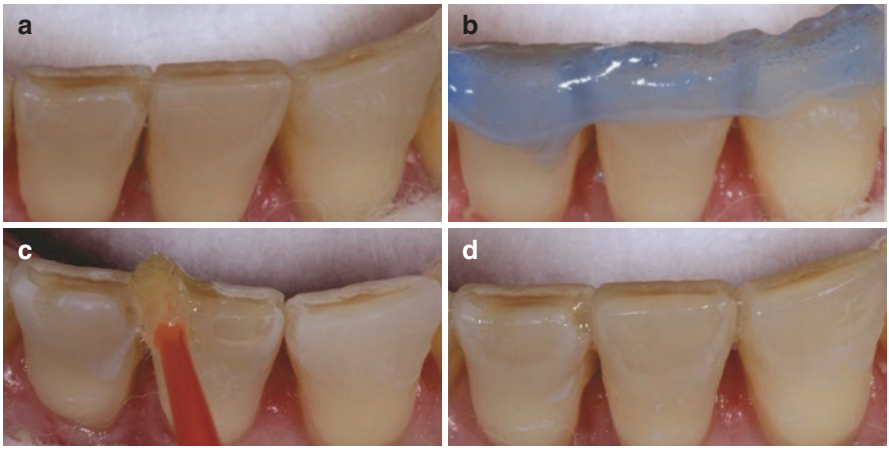

Fig. 4.16 (**a**) Incisal region with exposure of dentin tissue. (**b**) Conditioning using the total-etch technique. (**c**) Application of the adhesive material. (**d**) Teeth are ready to start the bleaching procedure

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

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