Effect of bleaching on restorative materials and restorations—a systematic review

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Summary Objective: Internal and external bleaching procedures utilizing 3–35% hydrogen peroxide solutions or hydrogen peroxide releasing agents, such as carbamide peroxide or sodium perborate, can be used for whitening of teeth. The purpose of the review article was to summarize and discuss the available information concerning the effects of peroxide releasing bleaching agents on dental restorative materials and restorations.

Sources: Information from all original scientific full papers or reviews listed in PubMed or ISI Web of Science (search term: bleaching AND (composite OR amalgam OR glass ionomer OR compomer OR resin OR alloy) were included in the review.

Data: Existing literature reveals that bleaching therapies may have a negative effect on physical properties, marginal integrity, enamel and dentin bond strength, and color of restorative materials as investigated in numerous in vitro studies. However, there are no reports in literature indicating that bleaching may exert a negative impact on existing restorations requiring renewal of the restorations under clinical conditions.

Conclusion: Bleaching may exert a negative influence on restorations and restorative materials. Advice is provided based on the current literature to minimize the impact of bleaching therapies on restorative materials and restorations.

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Introduction

Recent reviews underlined that both bleaching of discolored vital and non-vital teeth has a long and successful history [1,2]. For brightening discolored teeth, the use of hydrogen peroxide or peroxide releasing agents, such as carbamide peroxide or sodium perborate, has become a popular treatment modality. A recently published review showed that tooth bleaching teeth is comparatively safe in terms of potential risk for alteration of dental hard tissue [3]. This corresponds to the fact that macroscopically or clinically visible damage due to vital bleaching has not been described in the literature so far, although it is reported that bleaching of non-vital teeth using the walking-bleach-technique involves the risk of development of external cervical resorptions [1,4]. Despite the fact that vital bleaching is not regarded as creating macroscopically visible defects, there are numerous studies which exhibited microstructural changes of dental hard tissue induced by bleaching agents, especially when peroxides are applied in high concentrations [5]. Thereby, alteration of the histological aspects and composition of bleached enamel has been described [6–12].

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It was also reported that slight surface alterations, as assessed by scanning electron microscopy, and a decrease of surface microhardness and fracture toughness might occur due to bleaching of dental hard tissues [13–22]. These possible effects on dental hard tissues are discussed as being minimal and not relevant provided that the bleaching agents are applied in a sensible manner and according to the manufacturers’ instructions [1,19,20]. Beside these aspects regarding influence of bleaching agents on dental hard tissues, some clinicians also express concern about the effect of these agents on dental restorative materials [23,24].

The purpose of the present article is to summarize the available information concerning the effects of bleaching agents on dental restorative materials. All original scientific full papers or reviews listed in PubMed or ISI Web of Science (search term: bleaching AND (composite OR amalgam OR glass ionomer OR compomer OR resin OR alloy) were included in the review, but abstracts dealing with this topic were not taken into consideration. Case reports were included only when they exclusively report observations which were not described in other publications.

The influence of various bleaching agents on physical properties, surface morphology and color of different restorative materials, has been investigated in several in vitro-studies simulating the clinical situation as closely as possible. In those studies, home-bleaching products (10–16% carbamide peroxide) were generally used within a 2–4 week bleaching simulation with application intervals of 4–8 h per day. Tooth-whiteners designed for in-office-application (30–35% hydrogen or carbamide peroxide) were applied at treatment intervals of 15–60 min (as recommended by the manufacturers). These different bleaching regimes were preferably used in the studies reviewed and are therefore not repeatedly mentioned when describing and discussing the results of the respective studies. However, it should be borne in mind that the total time period of application was much higher for the low concentrated regimes than for the highly concentrated ones.

**Effect of bleaching agents on properties of restorative materials**

**Composite resins**

In some scanning electron microscopic studies and profilometric analysis, it was shown that 10–16% carbamide peroxide bleaching gels (i.e. 3.6–5.76% hydrogen peroxide) may lead to a slight, but statistically significant increase in surface roughness and amount of porosities of microfilled and hybrid composite resins [25–27]. These findings were not corroborated in a SEM-study applying 6% hydrogen peroxide gel on a hybrid composite in a cycling protocol with intermittent storage of the samples in pooled human saliva [28]. It is conceivable that storage in saliva might have modified or attenuated the hydrogen peroxide impact by formation of a surface-protection salivary layer on the restorative material. In microfilled specimens also, cracking was observed after application of 10% carbamide peroxide for the above mentioned period of 4 weeks [27]. Usage of tooth whiteners containing 30–35% hydrogen peroxide did not effect the surface texture as revealed with profilometrical analysis [29,30]. Similar results were described using 20 and 35% carbamide peroxide gel for 3 and 1 h per day, respectively, during a period of 14 days [31]. However, analysis of surface reflectance showed significant changes in microfilled and hybrid composite resins after application of highly concentrated tooth whiteners with 30–35% hydrogen peroxide [29]. The authors suggested that the changes in surface reflectance reveal more subtle changes in the surface and perhaps also in the immediate subsurface. In this context it should also be mentioned that salivary proteins absorbed onto the surface of composite materials decreased after bleaching with peroxide containing agents, which is suggested to have an influence on bacterial adhesion of cariogenic bacteria, such as *Streptococcus sobrinus* and *Streptococcus mutans*, but not of *Actinomyces viscosus* [32].

There is controversy about the impact of low concentrated 10–16% carbamide peroxide gels on surface microhardness of restorative composite materials. In some investigations softening of composite resins was associated with the application of home-bleaching gels [27,33]. Other investigations revealed no significant hardness changes [34,35] due to application of home-bleaching gels or even an increase in surface hardness [25,36]. In-office-tooth whiteners (35% carbamide peroxide or 35% hydrogen peroxide) did not significantly affect hardness and tensile strength of composite materials [37,38].

For standardized and reproducible evaluation of color changes of restorative materials, colorimeters are used analyzing L*a*b* values according to the CIELab-system [39,40]. It has been claimed that under clinical conditions in the mouth, ΔE color differences have been reported to be relevant and perceptible only when higher than 3.3 [41] or 3.6 [42]. Application of 10% hydrogen peroxide or
heated 30% hydrogen peroxide resulted in composite color changes which were presumably clinically detectable with $\Delta E^*$ ranging between 2 and 11 for the different materials and shades tested [43,44]. In contrast, use of 10% carbamide peroxide gel led to color changes of composite resins less than $\Delta E^* = 2$ and these were comparable to color changes of unbleached samples stored in water only [44,45]. However, even 10% carbamide bleaching agents were able to remove extrinsic stains from composite restorative materials [46].

**Polyacid-modified resin-based composites, resin-modified glass ionomer cements, glass ionomer cements and zinc oxide cements**

Highly concentrated bleaching regimes induced surface degradation, softening, an increase in fluoride release and changes in the coefficient of thermal expansion of polyacid-modified resin-based composites (compomers) when those bleaching agents were continuously applied for 1–5 days [47,48]. In some products, even cracks were observed on the surface of the specimens. However, a total of three 30-min bleaching sessions conducted at 1-week intervals, as recommended by the manufacturers, did not result in detrimental effects of the surface finish of compomers, resin-modified glass ionomer cements or glass ionomer cements [30]. In contrast, after treatment with 10–16% carbamide peroxide bleaching gels, an increase in surface roughness for some brands of those materials were noted, while other gels displayed decreased surface roughness, suggesting that the effects of the gels seem to be material dependent [25,26]. Jefferson et al. [49] examined alterations of atomic weight percentages in glass ionomer cement after contact with 10% carbamide peroxide with pH 4.5 and reported that the matrix of the specimens showed surface wash-off and corrosion with the cores of the silica more exposed and a decrease of surface aluminum content. In contrast to these findings, both high and low concentrated bleaching agents did not show any influence on fluoride release of dental materials, such as conventional and resin-modified glass ionomer cements [50]. Additionally, it was recently proved that a low concentrated 6% hydrogen peroxide gel did not cause significant dissolution or increased wear rate of glass ionomer cements [51].

The occurrence of visible color changes in compomers treated with 10% carbamide peroxide were, likewise, the changes in surface texture, dependent on the brand tested, whereas treatment with 10 and 30% hydrogen peroxide resulted in noticeable color change irrespective of the compomer material evaluated [44,52]. Superficial, extrinsic stain could be removed successfully with 10% carbamide peroxide from resin-modified glass ionomer cement, but not from a polyacid-modified resin-based composite [46]. Microhardness of resin-modified glass ionomer cements increased [33] or remained stable [36] after treatment with 10% carbamide peroxide gels. Utilizing highly concentrated bleaching regimes, no surface microhardness changes were observed in polyacid-modified resin-based composites or resin-modified glass ionomer cements [38].

**Feldspathic porcelain**

The only investigations on the effect of bleaching agents on ceramic restorative materials were performed by Turker and Biskin [25,33], who evaluated the effects of bleaching agents on feldspathic porcelain. They observed that 10–16% carbamide peroxide gels (applied for 8 h per day for 30 days) were able to significantly decrease surface hardness of the porcelain material tested. However, surface texture was not effected by the bleaching regimen, as also reported in an SEM investigation by Schemehorn et al. [28], when applying a 6% hydrogen peroxide gel on feldspathic porcelain.

**Provisional materials**

Jefferson et al. [49] described a decrease in aluminum and an increase in porosity in zinc oxide cement after immersion in acidic 10% carbamide peroxide solutions. Zinc oxide surface levels of IRM fillings were significantly reduced due to influence of 10% carbamide peroxide, but not after application of 10% hydrogen peroxide, which, however, led to cracking and expansion of the tested material [53]. The color of provisional restorative materials designed for fabrication of crowns were reported to change after 14 days of simulated bleaching with 10% carbamide peroxide gel dependent on the provisional material tested. Thereby, methacrylate-based materials showed a shift to orange or dingy, whereas polycarbonate crowns and bis-acryl composite resin provisional material were not discolored [54].

**Amalgam and other dental alloys**

Low concentrated hydrogen peroxide gels (6%) do not alter the surface texture of either high-copper amalgam or type III gold alloy [28]. However, evaluation of corrosion current density of various dental alloys revealed that the application of 10%
carbamide peroxide solution on non-polished amalgam samples and nickel–chromium specimens may cause corrosion of these materials, but not of noble alloys. In this study, it was also shown that the bleaching agent caused lower corrosion potential for the polished amalgam samples compared to non-polished specimens [55]. Beside this study, revealing the alteration of corrosive potential of some dental alloys, various laboratory studies have reported increased release of amalgam components, such as mercury and silver, from amalgam specimens exposed to 10% carbamide peroxide or 10% hydrogen peroxide preparations [56–58]. Active oxidation was held to be responsible for the increased release of amalgam components and also for greening of the tooth-amalgam interface clinically observed by Haywood [59] during extended 10% carbamide bleaching. In vitro studies showed that the amount of mercury release was dependent on both the amalgam and carbamide peroxide brand tested [56,57,60]. Also, increasing carbamide peroxide concentrations led to an increase in amalgam mercury release. Thereby, the mercury release ranged from 0 to 30 times as much as compared to the controls which were stored in saline or phosphate buffer solutions [58,60,61]. The mercury release from amalgam seems also to be modified by the presence of biofilm on amalgam containing saliva, bacteria and polysaccharide, since an experimentally induced biofilm coating on amalgam has shown to reduce mercury release into the surrounding environment [62]. However, it should be noted that the above mentioned experiments had been conducted in vitro and that the mercury release might be more pronounced than in the in vivo situation.

Reasons for the impact of bleaching agents on properties of restorative materials and clinical consequences

The alterations in color of the restorative materials have been attributed to oxidation of surface pigments and amine compounds, which have also been indicated as responsible for color instability of restorative materials over time. Differences in color change between different materials might be a result of different amount of resin and different degrees of conversion of the resin matrix to polymer [43]. Also surface phenomena, such as increase in porosities, are discussed as a result of the deleterious impact of the oxidizing bleaching agents on the polymer-matrix of resin-based materials [37]. Additionally, it was debated whether the negative influences of the oxidizing agents on the resin matrix led to water uptake of the restorative materials with complete or partial debonding of fillers causing reduced surface integrity and loss of hardness of the materials [30].

Unfortunately, in none of the above mentioned studies were investigated how far the induced porosities, increased surface roughness and reduction in surface hardness of the tested materials led to recommendable need for replacement of existing restorations after bleaching to ensure longevity of the restorations. Therefore, it remains speculative whether these changes of surface texture and hardness are relevant under clinical conditions or if they are barely a surface phenomenon, which could be removed by simple polishing of restorations. However, polishing of the restorations after bleaching is advisable at least, since the increased surface roughness is held to be responsible for increased adherence of certain cariogenic microorganisms to the outer surface of tooth-colored restorative materials after contact with different bleaching agents as assessed by Mor et al. [63].

The oxidizing effect of the bleaching agents is also held responsible for the observed higher rate of mercury release from amalgam. In order to reduce patient exposition to amalgam components, polishing of amalgam restorations prior to starting of a bleaching therapy should be performed to reduce corrosion potential of the amalgam restorations. Additionally, pre-coating of amalgam surfaces with a protective varnish such as copalite (10% copal resin in a combination of ether, alcohol and acetone) seems to be advisable to reduce release of mercury into the surrounding environment during bleaching with 10% carbamide peroxide [57].

Effect of bleaching agents on bond strength of restorative materials to enamel and dentin

Bond strength of composite resins to enamel

Numerous studies have addressed the question whether various bleaching procedures effect the bond strength of composite resins to enamel specimens prepared from bovine or human teeth. Only one study was available which considered this aspect using resin-modified glass ionomer cement [64]. The overwhelming majority of studies utilizing 25–35% hydrogen peroxide uniformly showed that both shear bond strength and tensile bond strength of all composite restorative materials tested were significantly reduced when composite application (including acid-etching pretreatment) was
performed immediately, i.e. within 1 day, after completion of bleaching regime [65–72].

This was true irrespective of the application time (5, 30 or 60 min, respectively) of the 35% hydrogen peroxide solution during the bleaching procedure [66–70]. It was shown that resin tags in bleached enamel subsequently acid etched with 37% phosphoric were less defined, more fragmented and penetrated to a lesser depth than in unbleached enamel controls [69].

Teixeira et al. [74,75] simulated the walking-bleach-technique by placement of various highly concentrated bleaching agents into the pulp chamber of tooth specimens for 4 weeks. Enamel bond strength of composite materials tested on enamel slabs prepared from those teeth was only reduced when a mixture of sodium perborate with 30% hydrogen peroxide was applied, but not after use of either 37% carbamide peroxide or a mixture of sodium perborate with water. This reduction in shear bond strength was valid until a 7-d-post-bleaching period elapsed before bonding. Studies investigating the appropriate time point for bonding of composites to enamel after termination of in-office bleaching with 25–35% hydrogen peroxide reported that bond strength returned to normal values when the composite was applied on the specimens 24 h [65] or 2 weeks [72] after bleaching. Other studies also showed that a delay of 1 week was not long enough to allow for optimal bonding [66,67,73,76], although peroxide completely leaches from 35% hydrogen bleached enamel already within 7 days after application [77].

Only a single investigation suggested that bond strength of brackets bonded to acid etched enamel immediately after in-office bleaching with 35% hydrogen peroxide was not significantly affected [78]. However, failure analysis showed that unbleached controls primarily failed at the bracket/adhesive interface, whereas bleached groups either showed cohesive failures within the adhesive or failed at the adhesive/enamel interface as also reported in other investigations [70]. This finding, therefore, also supports the assumption that the adhesion of resin to bleached enamel and also the properties of the adhesively attached resin are negatively affected by the bleaching procedure performed before bonding.

Also, most of the studies investigating the influence of carbamide peroxide gels on adhesive-ness of enamel revealed reduction of enamel composite bond strength compared to unbleached enamel [66,79–82]. Thereby, bond strength reduction was similar for carbamide peroxide gels concentrated between 10 and 20% [83]. Only few studies did not find a negative impact of carbamide peroxide (10%) bleaching on composite-enamel bond strength [17,64]. Similar to the bond strength reduction described above for enamel bleached with highly concentrated hydrogen peroxide solutions, the bond strength return to normal values when the composite is applied to the enamel after a time lapse. Recommendations for application of composite materials onto carbamide peroxide bleached enamel ranged from 1 day [79], 3–7 days [66,84], to 3 weeks [83]. The effect of bonding agent on composite bond strength to enamel bleached with carbamide peroxide gel seems to depend on the bonding agent used [85]. However, controversy exists whether acetone-based adhesive systems are generally able to reverse the negative effects of carbamide peroxide bleaching on composite enamel bond strength. Sung et al. [85] reported that a significant difference between acetone-based adhesive aided bond strength for bleached and unbleached enamel was registered, but not for the alcohol-based adhesive tested. In contrast, other authors reported that an acetone-based adhesive and also other water-clearing solvents, such as pure acetone or alcohol, were able to significantly reduce the adverse effects of bleaching on composite-enamel bond [82,86].

Only one study dealt with the adhesion of resin-modified glass ionomer cements to pre-bleached enamel. It was shown that the resin-modified glass ionomer cement used for bracket bonding was not affected by pre-bleaching of enamel with 10% carbamide peroxide at 24 h and 14 days after bleaching [64].

**Bond strength of composite resins and glass ionomer cements to dentin**

Bond strength of restorative materials to dentin has not been investigated intensively. The few studies which are available reported unanimously about a reduction of dentin bond strength for composite and glass ionomer cements for both bleaching with 30–35% hydrogen peroxide and 10–21% carbamide peroxide [76,87–91]. This finding was true irrespective of the adhesive systems used for bonding of composite materials. In most of the studies, reduction in bond strength was, like the effect in enamel, still present after an elapse of 7 days before application of the tested materials to the bleached dentin specimens [76,87,89]. Only Demarco et al. [91] reported that dentin bond strength of composite was not impaired when bonding was delayed for 1 week after bleaching treatment with 30% hydrogen peroxide.
Reasons for the impact of bleaching agents on bond strength of restorative materials and clinical consequences

Several aspects are held to be responsible for the reduction in composite bond strength to bleached enamel and dentin. Bleaching with hydrogen peroxide or hydrogen peroxide-releasing agents may result in significant decrease of enamel calcium and phosphate content and in morphological alterations in the most superficial enamel crystallites [8,92]. Moreover, acid etching of bleached enamel surface produced loss of prismatic form resulting in an enamel surface which appeared to be over-etched [17]. Additionally, it was suggested that the enamel and dentin organic matrix was altered by the oxidizing effect of hydrogen peroxide [93,94]. These aspects may lead to an enamel surface, which did not allow for formation of a strong and stable bond between the composite applied and the superficial etched enamel layer. Furthermore, reduction in bond strength in hydrogen-peroxide-treated enamel and dentin could be caused by residual oxygen present in enamel and dentin pores after completion of the bleaching treatment. Liberation of the oxygen could either interfere with resin infiltration into enamel and dentin [66,76] or inhibit polymerization of resins that cure via a free-radical mechanism [95]. The latter aspect might result in oxygen-inhibited polymerization of the composite components directly in contact with the dental hard tissues leading to a soft interface not able to withstand debonding forces sufficiently. Interestingly, SEM examinations demonstrated that acid etching following 30% hydrogen peroxide usage did not totally remove the smear layer on dentin surfaces [91]. This fact might presumably impair the interaction between dentin adhesives applied with total-etching technique and dentin. For the glass ionomer cement it is also discussed that the setting of the cement is inhibited by oxygen remnants [87]. The recommendations for a 1–3 week delay before placement of composite or glass ionomer restorations after termination of bleaching therapy are made under the assumption that the residual oxygen may have sufficient time to leach from the dental hard tissues. To dissolve remnants of peroxide, cavities can also be cleaned with catalase or 10% sodium-ascorbate [96–99]. However, application of these agents might be time-consuming or expensive, so that further investigations are needed to optimize their use under clinical conditions. It is therefore more feasible to follow the above mentioned recommendations to allow for contact time of at least 7 days with water to avoid the reduction of adhesion of composites to enamel [67,73,77]. Optimal bonding to pre-bleached dental hard tissue could be achieved after a period of about 3 weeks [83,100].

Effect of bleaching agents on marginal quality of restorations

Composite resins

Pre-restorative non-vital, intra-coronal bleaching in the sense of walking-bleach technique using mixtures of 37% carbamide peroxide or pastes consisting of 30% hydrogen peroxide and sodium perborate leads to a higher rate of microleakage in composite restorations of both the access cavity and class-V cavities placed immediately after termination of bleaching [75,100–102]. In class-V restorations, the increase of microleakage after intra-coronal application of 37% carbamide peroxide was only detected in dentin margins and not in enamel margins [100]. The rate of microleakage of restored access cavities increased with increasing duration of the application of the sodium perborate-hydrogen peroxide mixture [102]. Thereby, a 7-day application resulted in inferior sealing compared to a 1- or 4-day application. Short-term use of intracoronal calcium hydroxide medicament for 7 days after completion of walking-bleach therapy was able to reverse the negative influences of the hydrogen peroxide application on microleakage of access cavities [101].

Controversy exists about the influence of pre-operative external bleaching with 10% carbamide peroxide on microleakage of composite restorations. Crim [103] reported that 10% carbamide peroxide did not impair the marginal seal of class-V restorations placed at the cementoenamel junction. In contrast, in a study by Ulukapi et al. [104], microleakage rates of labial restorations with enamel margins only, were significantly increased after 10% carbamide peroxide bleaching. Similar findings were reported by Turkun and Turkun [96], who observed significant reduction in sealing of access cavities with composite resins up to 1 week after application of 10% carbamide peroxide into the pulp chamber.

Two studies reported that the post-operative contact of composite restorations with 35% hydrogen peroxide or 10–16% carbamide peroxide gel adversely affected the marginal seal at both dentin [105] and enamel [104] margins. In contrast, other studies did not find increased microleakage rates at least at enamel margins [105,106].
Polyacid-modified resin-based composites, resin-modified glass ionomer cements, amalgam and temporary materials

Only two studies addressed to the impact of post-operative bleaching (35% hydrogen peroxide or 3–16% carbamide peroxide) on restorations with enamel margins fabricated with polyacid-modified resin-based composites, resin-modified glass ionomer cements or amalgam [104,106]. In both studies, no deterioration of marginal seal was revealed. Marginal leakage of amalgam restorations with enamel margins only were also not negatively influenced by pre-operative external bleaching with 10% carbamide peroxide [104].

It was indicated that temporary restorative materials, such as TERM, zinc-oxide-eugenol cement and zinc oxide phosphate cement, did not provide an optimal seal when used for provisional restoration of the access cavity during internal bleaching with the walking-bleach technique using a mixture of 30% hydrogen peroxide with sodium perborate as bleaching agent [107,108]. That was also true for composite materials applied without acid-etching technique when tested for provisional seal of the access cavity [107]. The most favorable results with respect to cavosurface seal during internal bleaching were demonstrated for hydraulic filling materials, such as Cavit and Coltosol [107].

Penetration of the pulp chamber by bleaching agents in restored teeth

It was observed that during external bleaching with 30% hydrogen peroxide or 10–35% carbamide peroxide gel higher levels of hydrogen peroxide penetrated into the pulp chamber in teeth with restorations placed in enamel as compared to sound teeth [109,110]. This was true for restorations fabricated with either composite materials, polyacid-modified composite resins or resin-modified glass ionomer cements. Furthermore, it was shown that higher concentrated carbamide peroxide gels (35%) lead to distinct higher levels of peroxide in the pulp chamber compared to low (10%) concentrated gels [111].

Clinical consequences of the impact of bleaching agents on restorations

The above mentioned studies underline that pre- and post-operative bleaching procedures may negatively affect marginal seal of restorations. Moreover, restorations and margins of restorations could be regarded as a possible pathway facilitating peroxide penetration into the pulp chamber. Peroxide penetration into the pulp chamber is held responsible for pulpal reactions, such as increase in tooth hypersensitivity, during external bleaching of vital teeth [112,113]. Dentists should therefore examine restorations meticulously before starting a bleaching therapy and renew insufficient fillings prior to bleaching in order to achieve an optimal seal of the pulp chamber and thus reducing the risk of adverse effects. Future studies must investigate how far the higher rate of microleakage observed in vitro lead to problems with existing restorations in the clinical situation.

Conclusions

Bonding of adhesively attached restorations to pre-bleached dental hard tissue is significantly reduced. Therefore, it is recommended to delay placement of restorations after termination of bleaching therapy for at least 1–3 weeks. Additionally, bleaching therapies with hydrogen peroxide or hydrogen peroxide releasing preparations may have a negative effect on restorations and restorative materials as shown in numerous in vitro investigations. It remains unclear in how far those observations may result in significant deterioration of restorations under clinical conditions. However, there are no reports in the literature indicating that bleaching may exert any negative impact on existing restorations thereby requiring renewal of the restorations. Nevertheless, further investigations are necessary to elucidate these aspect more precisely.

References

Bleaching and restorative materials


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