Effect of light energy on peroxide tooth bleaching

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ABSTRACT

Background. Light-activated bleaching is a method of tooth whitening. The authors conducted a study to compare the whitening effects and tooth temperature changes induced by various combinations of peroxide bleaches and light sources.

Methods. The authors randomly assigned 250 extracted human teeth halves into experimental groups (n = 10). A placebo gel (control), a 35 percent hydrogen peroxide or a 10 percent carbamide peroxide bleach was placed on the tooth surface and was irradiated with no light (control); a halogen curing light; an infrared, or IR, light; an argon laser; or a carbon dioxide, or CO_2, laser. Color changes were evaluated immediately, one day and one week after treatment using a value-oriented shade guide and an electronic dental color analyzer. The outer enamel and inner dentin surface temperatures were monitored before and immediately after each 30-second application of light using a thermocouple thermometer.

Results. Color and temperature changes were significantly affected by an interaction of the bleach and light variables. The application of lights significantly improved the whitening efficacy of some bleach materials, but it caused significant temperature increases in the outer and inner tooth surfaces. The IR and CO_2 laser lights caused the highest tooth temperature increases.

Conclusions. Dentists performing an in-office bleaching technique with the use of an additional light source to accelerate tooth whitening should consider the specific bleaching agent being used, as well as the potential risks of heating teeth.

Clinical Implications. A specific combination of bleach and light that demonstrates good color change and little temperature rise should be selected for in-office tooth bleaching.

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Vital tooth bleaching is a popular treatment modality in dentistry.[1] The advantages of an in-office whitening procedure over an at-home bleaching technique include dentist control, avoidance of soft-tissue exposure and material ingestion, reduced total treatment time and greater potential for immediate results that may enhance patient satisfaction and motivation. The typical in-office bleaching regimen involves the application of a 35 percent hydrogen peroxide formulation to the tooth surface.

Successful vital bleaching requires good whitening efficacy without pulpal damage.

Proponents of "power bleaching" claim to reduce the total in-office bleaching time necessary by energizing the bleach material using various light sources, such as lasers and plasma arc lights. The theoretical advantage is the light source's ability to heat the hydrogen peroxide, thereby increasing the rate of decomposition of oxygen to form oxygen free radicals and enhancing the release of stain-containing molecules.[2] In one study, various light sources elevated the bleach temperatures[3]; however, they also increased the intrapulpal temperature. Therefore, astute clinicians should consider the issue of pulp health before rendering this treatment on vital teeth.

With respect to esthetics, our literature review showed that power bleaching has questionable whitening efficacy. Jones and colleagues[4] demonstrated that a typical in-office laser bleaching session produced significantly fewer desirable color changes than did two at-home bleaching protocols. An article published in CRA Newsletter also reported no perceivable difference between energized versus nonenergized bleaching when performed under standardized conditions.[5,6] In contrast, a recent study suggested that bleaching using a plasma arc lamp enhanced the whitening of the superficial and deeper layers of tooth structure, thus causing a significant change in tooth color.[7] Further scientific evidence is needed to substantiate these findings.

Light is absorbed, scattered, transmitted or reflected by a material. Most bleaching agents that have been developed for combined use with light sources include the addition of an activator or colorant to improve light absorption or to reduce tooth heating. Our preliminary work on the energy absorption characteristics of hydrogen and carbamide peroxide showed that selected bleaching materials (without colorants) strongly absorb light that has wavelengths less than 300 nanometers (in the ultraviolet range), from 2,800 to 3,600 nm and more than 6,000 nm. Such information suggests that the existing light sources used for tooth whitening that have an output in the 400 to 500 nm range of the color spectrum would be absorbed poorly by bleaches without colorants. We speculated that a light source with a spectral output in the range that is strongly absorbed by bleach would best enhance tooth bleaching.

The purpose of this in vitro study was to compare the tooth whitening effects and tooth temperature changes induced by various combinations of peroxide bleaches and light sources.

TABLE 1

VALUE-ORIENTED VITA LUMIN SHADE GUIDE* RANKINGS USED FOR SHADE TAB COLOR ASSESSMENTS.

VALUE	VITA LUMIN SHADE	ASSIGNED NUMERICAL COLOR RANKING
Lightest	B1	1
	A1	2
	B2	3
	D2	4
	A2	5
	C1	6
	C2	7
	D4	8
	A3	9
	D3	10
	B3	11
	A3.5	12
	B4	13
	C3	14
	A4	15
Darkest	C4	16

* The Vita Lumin Shade Guide is manufactured by Vita Zahnfabrik H. Rauter GmbH & Co., Bäd Sackingen, Germany.

MATERIALS AND METHODS

We randomly selected 125 human teeth that had been extracted within three months of experimentation. The teeth were cleaned and stored in distilled water at 4 C. All of the teeth had no or minimal caries and restorations, had no enamel cracking and were a shade B2 or darker on the Vita Lumin Shade Guide (Vita Zahnfabrik H. Rauter GmbH & Co., Bäd Sackingen, Germany). We divided the teeth into buccal and lingual halves using a high-speed handpiece, water irrigation and carbide burs. We then randomly assigned the tooth halves into 25 groups of 10. All of the teeth maintained a wet or moist condition during all phases of the experiment.

One trained evaluator (K.L.) assessed the baseline shades of the teeth using the shade guide and a prototype electronic dental color analyzer. The shade guide can be ranked according to value (Table 1); a lower numerical value for shade denotes a lighter tooth shade. The electronic color analyzer assesses dental colors by calculating numerical values of brightness (B parameter) and level of colorization (C parameter) from measured spectral reflectance. A more positive B parameter and more negative C parameter represent improved color change compared with baseline measurement.

We took photographs of the teeth before bleaching and a matching Vita shade tab of the teeth to be bleached under standardized lighting

TABLE 2

BLEACHING MATERIALS USED FOR IN VITRO TOOTH WHITENING.

BLEACHING MATERIAL	MANUFACTURER	ACTIVE INGREDIENT
Placebo Gel (Control)	Ultradent Products, South Jordan, Utah	None
Opalescence Xtra	Ultradent Products	35 percent hydrogen peroxide
QuickWhite Laser Whitening System	LumaChem, West Jordan, Utah	35 percent hydrogen peroxide
StarBrite Power Pack	Interdent, El Segundo, Calif.	35 percent hydrogen peroxide
Nupro Gold Teeth Whitening Gel	Dentsply International, York, Pa.	10 percent carbamide peroxide

conditions and away from strong light absorbers such as dark-colored walls using a digital camera (DSC-D770, Sony, Tokyo).

We fabricated 2-millimeter thick ethylene vinyl acetate molds with 3-mm wide apertures using a vacuum-forming device to fit the facial or lingual surface of each specimen. The acetate molds held the probe of the color analyzer perpendicular to the same surface area of the tooth so that we could obtain repeated color measurements. We tested the teeth's middle one-thirds because the translucency of the incisal edge could make the color dependent on the background.

We placed each peroxide bleaching gel in an approximately 2-mm thickness on the outer enamel surface of 50 teeth (Table 2). We also placed a colorless glycerine-based placebo gel that contained no hydrogen or carbamide peroxide (the no bleach control) on 50 teeth. We placed the inner dentin surfaces on gauze pads soaked with water to prevent tooth dehydration.

The light sources we used were no light irradiation (control); a halogen curing light; a prototype infrared, or IR, bleaching light; an argon laser; and a carbon dioxide, or CO_2, lasers (Table 3). Our protocol for applying the light sources was based on the manufacturers' directions for the two hydrogen peroxide bleaches that prescribed the use of light application (Opalescence Xtra, Ultradent Products, South Jordan, Utah; QuickWhite Laser Whitening System, LumaChem, West Jordan, Utah). We directed the light sources onto the bleaches from a distance of 1 to 2 mm for 30 seconds. We then left the bleaching gel on the tooth surfaces for 180 seconds before rinsing it off. For each tooth, we repeated this bleach and light application six times sequentially for a 21-minute total exposure to the bleach material and a three-minute total exposure to the light source.

We measured the temperature of each tooth's outer enamel and inner dentin surfaces before and after each 30-second application of light using a thermocouple thermometer. We used the temperature data to calculate a mean outer enamel temperature increase and a mean inner dentin surface temperature increase after each 30-second light application for each tooth. For the

TABLE 3

LIGHT SOURCES USED FOR IN VITRO TOOTH WHITENING.

LIGHT SOURCE	MANUFACTURER	WAVELENGTH (NANOMETERS)	POWER
No Light (Control)	NA*	NA	NA
Spectrum Halogen Curing Light	Dentsply International, York, Pa.	400-500	500-600 milliwatts
Prototype Infrared Light	EFOS, Mississauga, Ontario, Canada	2,000-4,000	2.8-3.2 watts
Argon Laser	Synrad, Mukilteo, Wash.	488	200 mW
Carbon Dioxide Laser	Synrad	10,600	600 mW

* NA: Not applicable.

control group (no light application), we measured the temperature immediately after the bleach applications and 30-seconds thereafter. The recorded ambient room temperature was 23.5 C ± 0.8 C standard deviation during experimentation.

We evaluated the posttreatment tooth color without knowledge of the pretreatment color assessment immediately after the bleaching session. We then stored the teeth in distilled water and incubated them at 37 C. After one day and after one week, we evaluated the posttreatment tooth color again without knowledge of the pretreatment color assessment and experimental treatment. We took photographs of each tooth with matching shade tabs immediately and one week after bleaching to document the tooth color.

We analyzed the color assessment and temperature data by analysis of variance, the Kruskal-Wallis test and the Duncan multiple range test for pairwise contrasts ($P < .05$).

The no-light-application groups had the lowest mean elevations in tooth temperature regardless of bleach type.

RESULTS

After rinsing, the outer enamel and inner dentin surfaces reverted to their baseline temperatures before light application. Table 4 shows the mean temperature increases in the outer and inner tooth surfaces after each 30-second light exposure for the 25 combinations of bleach and light treatments. The control (no-light-application) groups had the lowest mean elevations in tooth temperature regardless of bleach type. Both outer and inner surface temperature changes were affected significantly by an interaction of the type of light application and bleach material used ($P < .05$). The groups exposed to IR light and a CO_2 laser showed, respectively, the highest and second highest mean increases in outer or inner surface temperature. The degree of temperature increases in these groups was affected significantly by the type of bleach.

Similarly, the immediate, one-day and one-week color change parameters were affected significantly by an interaction of the type of light application and bleaching material ($P < .05$). The rankings for the effectiveness of tooth lightening varied, depending on the time of color assessment and the parameter being considered. The effect of the different types of light, regardless of bleach type, was best reflected in the immediate B parameter results (Figure 1, page 199). Conversely, the effect of the different types of bleaches was best reflected in the one-week C parameter and shade tab ranking results (Figure 2 and Figure 3, page 199).

At one week, the placebo gel groups exhibited little change in the color assessment parameters compared with baseline regardless of the type of light irradiation. For the Opalescence Xtra bleach, the use of the halogen light elicited significantly more changes in the C and shade tab rankings compared with the no-light-application groups at one week. For the QuickWhite bleach, the IR light significantly improved the C parameter and shade tab rankings compared with the no-light-application groups at one week.

DISCUSSION

The standard deviations for all the color parameter changes were high, which suggests that there was a wide variation in individual tooth responses to different bleach and light treatments. With regard to temperature measurements, the standard deviations were not high, indicating that there was a more consistent thermal response in the individual teeth to different bleach and light treatments. Factors that would have influenced the temperature changes include individual tooth properties and the variable thickness of the applied bleaching material.

Color assessments for bleaching have been made using value-oriented shade guides,[8-12] colorimeters[2,13-16] and digitized photographs.[17] The value-oriented shade guide gives clinically relevant results because successful bleaching calls for a perceivable difference in tooth color. However, the selection of the matching shade tab is subjective, not predictably reproducible and influenced by such factors as lighting and eye fatigue.

The use of the colorimeter also has its advantages and drawbacks; it gives more objective results than shade tabs, but it is affected by tooth translucency, tooth contour, tooth texture and difficulties in repeatable tooth repositioning. The L* (lightness) and b* (yellow/blue) pretreatment colorimeter results were shown to be affected consistently by bleaching procedures, but no significant differences were found in the a* (red/green) measurement.[2,14] To simplify the quantification of color change, the differences in the three L*, a* and b* colorimeter parameters have been inte-

TABLE 4

MEAN OUTER ENAMEL AND INNER DENTIN SURFACE TEMPERATURE INCREASE AFTER EACH 30-SECOND LIGHT APPLICATION.

GROUP NUMBER	LIGHT/BLEACH COMBINATION*	MEAN OUTER ENAMEL TEMPERATURE INCREASE (C)	MEAN INNER DENTIN TEMPERATURE INCREASE (C)
1	No light, placebo gel	0.14	0.16
2	No light, Opalescence Xtra	0.14	0.25
3	No light, QuickWhite	0.20	0.22
4	No light, StarBrite	0.29	0.76
5	No light, Nupro Gold	0.93	1.13
6	Halogen light, placebo gel	4.49	2.70
7	Halogen light, Opalescence Xtra	6.90	4.52
8	Halogen light, QuickWhite	4.81	3.61
9	Halogen light, StarBrite	4.75	3.76
10	Halogen light, Nupro Gold	6.25	5.52
11	Infrared, or IR, light; placebo gel	25.26	18.15
12	IR light, Opalescence Xtra	28.07	19.29
13	IR light, QuickWhite	27.80	21.67
14	IR light, StarBrite	28.19	21.56
15	IR light, Nupro Gold	29.27	23.48
16	Argon laser, placebo gel	2.77	2.50
17	Argon laser, Opalescence Xtra	3.07	2.80
18	Argon laser, QuickWhite	2.23	2.14
19	Argon laser, StarBrite	2.16	1.96
20	Argon laser, Nupro Gold	3.31	3.20
21	Carbon dioxide, or CO_2, laser; placebo gel	19.85	14.51
22	CO_2 laser, Opalescence Xtra	13.34	9.75
23	CO_2 laser, QuickWhite	10.73	6.93
24	CO_2 laser, StarBrite	13.08	7.98
25	CO_2 laser, Nupro Gold	22.26	16.55

* The products' manufacturers are listed in Table 2.

grated into a single ΔE* parameter.[13,15] Melnik and colleagues[18] also proposed an integrated C parameter that describes the level of dental colorization from absolute white, and they developed a novel algorithm of color determination for the color analyzer we used in this study. The B parameter represents brightness or the amount of light backscattered from the tooth, and the C parameter represents the relative spectral deviation from absolute white. The use of the B and C parameters is new, and we made no attempt in this study to analyze their individual contributions to the overall color perception. We noted, however, that the B parameter at the time imme-

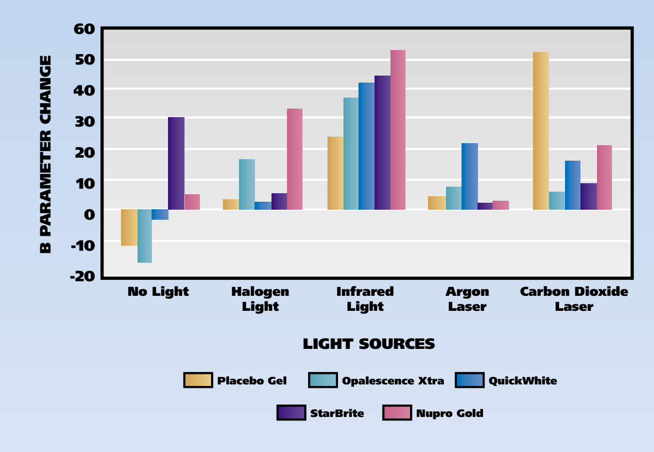

Figure 1. Mean changes in the B parameter immediately after in vitro tooth bleaching. Opalescence Xtra is manufactured by Ultradent Products, South Jordan Utah; QuickWhite Laser Whitening System is manufactured by LumaChem, West Jordan, Utah; StarBrite Power Pack is manufactured by Interdent, El Segundo, Calif.; Nupro Gold Teeth Whitening Gel is manufactured by Dentsply International, York, Pa.

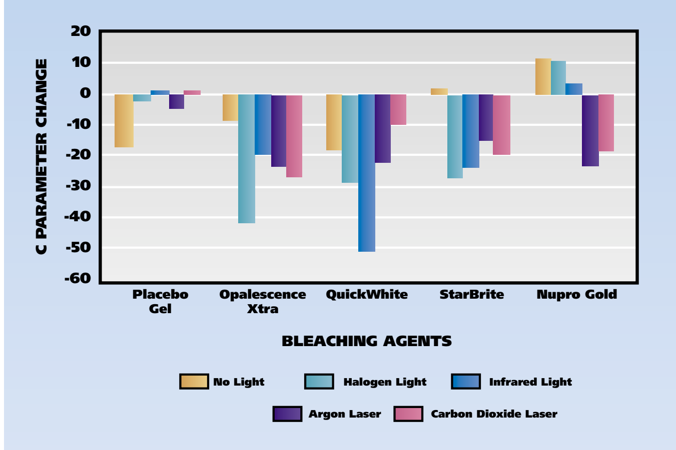

Figure 2. Mean changes in the C parameter one week after in vitro tooth bleaching. Opalescence Xtra is manufactured by Ultradent Products, South Jordan Utah; QuickWhite Laser Whitening System is manufactured by LumaChem, West Jordan, Utah; StarBrite Power Pack is manufactured by Interdent, El Segundo, Calif.; Nupro Gold Teeth Whitening Gel is manufactured by Dentsply International, York, Pa.

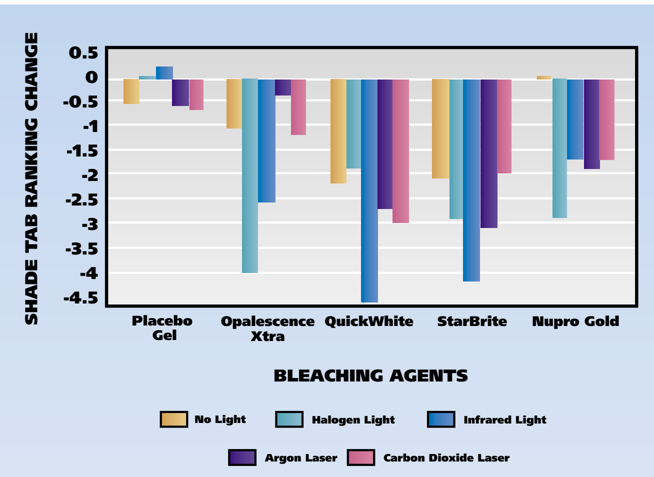

Figure 3. Mean changes in shade tab ranking one week after in vitro tooth bleaching. Opalescence Xtra is manufactured by Ultradent Products, South Jordan Utah; QuickWhite Laser Whitening System is manufactured by LumaChem, West Jordan, Utah; StarBrite Power Pack is manufactured by Interdent, El Segundo, Calif.; Nupro Gold Teeth Whitening Gel is manufactured by Dentsply International, York, Pa.

diately after bleaching and light irradiation was affected most by the type of light application. After one week, the shade tab ranking and the C parameter were affected most by the bleach material that was used. In this study, we considered the one-week color changes to be more important than the immediate color changes for assessing the effectiveness of bleaching.

Temperatures between 46 C and 51 C have been advocated for bleaching nonvital teeth.[19] In 1965, Zach and Cohen[20] showed that intrapulpal temperature increases of 5.5 C caused irreversible pulpitis in 15 percent of the teeth tested, and Schubert[21] regarded 41.5 C as the threshold beyond which pulpal inflammation occurs. The in vitro nature of our study limits the conclusions that can be drawn, because pulpal blood flow helps stabilize the pulpal temperature increase in vivo.[22] However, the large temperature increases in the outer and inner tooth surfaces that we observed for the CO_2 laser and especially the IR light groups, regardless of bleach type, suggest that there is a strong likelihood of pulpal damage using these light sources for 30 seconds during vital tooth bleaching. The CO_2 laser is less preferable than the argon laser for bleaching because of the potential thermal adverse effects associated with the CO_2 laser.[23]

Tooth dehydration is a probable cause of immediate tooth lightening,[4,24] and it presumably is greater with increased tooth heating. In our study, the placebo gel groups demonstrated significantly greater immediate B parameter color changes when used with the CO_2 laser and IR light—the two light sources that caused the greatest increases in tooth surface temperature—compared with no light application, despite the lack of an active bleaching ingredient. The observed immediate tooth lightening that is attributable to tooth dehydration appeared to be due more to an increase in tooth brightness (B parameter) than to a decrease in the level of tooth colorization (C parameter). This rapid or immediate increase in brightness is desirable for improved patient satisfaction and motivation, especially if further in-office bleaching is planned, or as a kickoff for using the at-home vital tooth bleaching technique. Nonetheless, much of the immediate B parameter color change caused by the light or resultant tooth heating relapsed by day one and one week. Clinicians should weigh the benefit of the transient increase in tooth brightness associated with the light groups with high thermal character against the potential for tooth sensitivity and adverse pulpal risks.

Both the halogen light and argon laser groups caused significantly less tooth heating than did the CO_2 laser and IR light groups. In general, there were lower temperature increases in the argon laser groups compared with the halogen light groups. The temperature increases during resin-based composite polymerization also have been reported to be lower for argon lasers than for halogen curing lights.[25]

The StarBrite Power Pack bleach (Interdent, El Segundo, Calif.), which contains no activators or colorants specific for light application, produced better C parameter color change results at one week with light application compared with no light application. QuickWhite is a whitening agent specifically formulated for bleaching with argon laser light. According to its manufacturer, it contains energy transfer crystals that are designed to absorb the argon laser light energy and transfer the converted thermal energy at a molecular level to the hydrogen peroxide. However, its most significant improvements in one-week C parameter and shade tab ranking color changes were induced by the IR light rather than by the argon laser. Compared with the no-light conditions, the argon laser did not significantly improve the one-week B parameter, C parameter or shade tab ranking color changes when used in combination with QuickWhite.

The manufacturer of Opalescence Xtra suggests that the addition of beta carotene improves the product's ability to absorb blue light. The maximum absorbance of beta carotene occurs at 450 nm. In this study, the one-week C parameter and shade tab ranking color changes for Opalescence Xtra were improved significantly by the use of a halogen light compared with no light applications. When combined with the argon laser light at 488 nm, however, Opalescence Xtra did not show improved color changes at one week compared with no light application. The outer enamel surface temperature increase after exposure to halogen light was higher when Opalescence Xtra was used than when the other bleaches were used. Yet, the degree of heat transmission from the outer to inner tooth surfaces was significantly less when Opalescence Xtra was used than when the other bleach groups were used after 30 seconds of halogen light irradiation, as reflected by a significantly higher difference between the outer and inner surface temperatures. These results suggest that beta carotene does improve the absorption of halogen light by the hydrogen peroxide bleach, resulting in less direct transmission of the energy to the tooth. However, the maximum inner surface temperature increase for this group was 5.5 C (mean inner surface temperature was 4.5 C). Therefore, it can be speculated that this bleach/light group still may pose a thermal risk to the pulp, particularly in thin teeth or teeth with pre-existing pulpal inflammation.

We included Nupro Gold Teeth Whitening Gel (Dentsply International, York, Pa.) in our study as a representative 10 percent carbamide peroxide bleach. It is marketed for use in at-home nightguard bleaching and typically is not used for in-office vital bleaching. It contains significantly less active bleach than does the 35 percent hydrogen peroxide bleaches that we tested in this study, and, in general, it displayed fewer C parameter color changes at one week. The greater changes we observed in the one-week C parameter for the higher concentration hydrogen peroxide bleaches compared with the 10 percent carbamide peroxide and placebo gel suggest that the observed tooth lightening associated with bleach exposure, as opposed to light exposure or temporary tooth dehydration, comes from a decrease in the level of tooth colorization rather than an increase in tooth brightness. The placebo gel, as expected, showed the least C parameter and shade tab ranking color changes at one week.

Successful vital bleaching requires good whitening efficacy without pulpal damage. It is possible that there is an optimum amount of time for light exposure that will enhance the whitening effect without excessively heating the tooth. Theoretically, the pulpal temperature increases associated with light application could be lessened by reducing the duration of light irradiation, increasing the thickness of the applied whitening agent, or increasing the absorption of light by the bleach, thereby decreasing the transmission of the light energy through the tooth. The benefits of universally using a light in in-office tooth bleaching still are uncertain. Further research is needed to determine the most favorable protocol for power bleaching.

CONCLUSION

Bleaching efficacy and tooth temperature changes were affected significantly by an interaction of the type of light application and bleaching material used ($P < .05$). The selection of bleaching material and technique depends on the tooth, as well as individual patient factors. Clinicians who perform in-office vital bleaching with an additional light source that is used to accelerate the whitening process need to consider the bleaching agent being used, as well as the potential risks associated with tooth heating. ■

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