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Assessment of the effectiveness of light-emitting diode and diode laser hybrid light sources to intensify dental bleaching treatment

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Abstract

Objective. To evaluate the effectiveness of the color change of hybrid light-emitting diode (LED) and low-intensity infrared diode laser devices for activating dental bleaching and to verify the occurrence of a color regression with time. ***Material and methods.*** A total of 180 specimens obtained from human premolars were immersed in a coffee solution for 15 days for darkening and then divided into eight experimental groups (n = 20 in each) as follows: G1, bleaching without light; G2, bleaching with halogen light; G3, bleaching with a blue LED (1000 mW/470 nm) and a laser device (120 mW/795 nm) simultaneously; G4, bleaching with an LED emitting blue light (1000 mW/470 nm); G5, bleaching with a blue LED (800 mW/470 nm) and a laser device (500 mW/830 nm) simultaneously; G6, bleaching with a blue LED device (800 mW); G7, bleaching with a green LED (600 mW/530 nm) and a laser device (120 mW/795 nm) simultaneously; and G8, bleaching with a green LED (600 mW). Three measurements were performed (at baseline and 14 days and 12 months after bleaching) using a Vita Easyshade spectrophotometer. The data were submitted to two-way ANOVA and a Tukey test. ***Results.*** All groups showed significantly higher ΔE values than Group G1, with the exception of Group G8. Variations in the ΔE values at 14 days were significant when compared with those obtained at baseline and after 12 months. ***Conclusions.*** Light activation of the bleaching gel provided faster and more intense bleaching than use of the bleaching gel without light activation. Combinations of low-intensity diode lasers are ineffective as a bleaching gel activator. Color regression was observed after 12 months of storage.

Key Words: *Laser, light-emitting diode, tooth bleaching*

Introduction

The in-office bleaching technique is a method of tooth bleaching that uses a hydrogen peroxide-based gel at a high concentration of ≈35%, which is applied to the teeth for a period ranging from 30 to 60 min [1]. The chemical process of dental bleaching consists of an oxide-reduction reaction, in which the quantity of pigments removed from the teeth is proportional to the time of enamel exposure to the bleaching agent within the pre-established limits for maintaining the health of dental structures [2]. As with any chemical reaction, supplying energy can accelerate its rate. For each 10°C increase in temperature, the reaction rate increases by a factor of 2.2 [3]. According to Goldstein & Garber [4], the temperature of the most effective bleaching agent for use in vital teeth ranges from 46 to 60°C.

More recently, new sources of energy have been tested to promote controlled heating of the bleaching gel, for example, halogen light photocuring devices, CO_2, diode, and argon lasers, plasma arc devices, and light-emitting diodes (LEDs). There are contradictory results in the literature regarding the effectiveness of photoactivator devices. Li et al. [5], Tavares et al. [6], Luk et al. [7], and Wong et al. [8] observed that use of light from a halogen lamp device significantly increased the effectiveness of bleaching treatment in

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comparison to application of a hydrogen peroxide gel only. Meanwhile, Papathanasiou et al. [1] and Hein et al. [9] found that use of light from halogen lamps did not whiten teeth more than application of the gel alone. Ploeger et al. [10] observed that the use of light does not affect the decomposition of hydrogen peroxide to levels that produce a clinically significant difference.

Several devices equipped with LEDs have been developed to provide energy for the bleaching reaction. In general, these LEDs emit light only at blue or green wavelengths and do not emit infrared radiation; thus they are unable to produce a heating effect [11,12]. However, when this light is absorbed by the colorants present in the bleaching gel, which are usually red or orange, it is converted into heat [13]. Nevertheless, there are insufficient scientific studies showing that these devices are actually more effective than the use of hydrogen peroxide alone, without any energy source to promote faster bleaching.

Another market trend is the association of LEDs with low-intensity diode lasers emitting at the near-infrared wavelength to promote a non-thermal, analgesic effect and biostimulation, reducing sensitivity during application and postoperatively [11]. These devices are called hybrid light sources. However, the question to be answered is whether these sources of energy have any effect on activation of the bleaching gel. Torres et al. [12], in 2007, found that a low-intensity infrared diode laser was able to speed the process of oxygen bubbles released by the bleaching agent, suggesting that it contributes to accelerating the reaction.

Given that there are so many possibilities, the professional can be influenced by the marketing industry to acquire high-cost equipment without proper scientific confirmation of its effectiveness. The purpose of this study was to evaluate the effectiveness of light-emitting devices equipped with LEDs and a low-intensity infrared diode laser to promote faster and more intense tooth bleaching than is obtained without the help of energy sources. The occurrence of a change in color 14 days and 12 months post-bleaching was also assessed. The first null hypothesis of the study was that light activation of the bleaching gel does not intensify tooth bleaching when compared to a group without light activation. The second null hypothesis tested was that variation in color at the different evaluation times (baseline, 14 days, and 12 months) after bleaching would not differ.

Material and methods

Ninety human premolars were used in this study. The teeth were collected after informed consent had been obtained under a protocol approved by the university committee. The roots were sectioned with a flexible diamond–steel disk in a handpiece until a distance of 2 mm from the cement–enamel junction was standardized. The tooth crowns were sectioned in the mesio-distal direction with a plaster-cutting appliance under water cooling in order to separate the buccal and lingual halves, resulting in 180 specimens.

The enamel surfaces were submitted to prophylaxis with a water and sodium bicarbonate jet using the Prophy Jet appliance. The specimens were immersed in an ultrasound bath for 10 min. Ten specimens were randomly selected and kept stored in distilled water at 37°C. The remaining 170 specimens were subjected to the darkening procedure. The dentin surfaces were etched with 37% phosphoric acid in gel for 15 s and then washed with an air/water jet for 30 s to expose the dentin tubules. For pigmentation, the teeth were immersed in 200 ml of a recently prepared 25% instant coffee solution (Nescafé; Nestlé, São Paulo, Brazil) and kept in a bacteriologic oven for 15 days at a temperature of 37°C [14]. The enamel surfaces were polished with diamond polishing paste and felt disks.

The exposed dentin surface of all specimens was etched with 37% phosphoric acid gel for 15 s and washed with an air/water jet for 30 s. It was applied Single Bond 2 adhesive system (3M ESPE, St. Paul, Mn, USA) according manufacturer's instructions. A thin layer of Z 250 composite (3M ESPE) was applied on the dentin surface and light-polymerized for 20 s. The purpose of this procedure was to prevent the artificial saliva and bleaching gels from penetrating into the dentinal tubules during the storage and bleaching procedures to which the teeth were submitted and interfering with the color.

The color of the enamel surfaces of the specimens was measured in three regions: the cervical third (1 mm above the cement–enamel junction); the middle third (central portion of the crown); and the occlusal third (1 mm from the edge of the cuspid) [15]. Three readings were taken using a Vita Easyshade spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) at different times: baseline and 14 days and 12 months afterwards.

The vestibular and lingual halves were randomly separated into control and experimental groups.

In the control group (n = 20), the specimens were divided into two subgroups:

- Negative control subgroup (n = 10): the specimens did not receive darkening or bleaching treatments and remained in distilled water at 37°C.
- Positive control subgroup (n = 10): the specimens received a darkening treatment but not a bleaching treatment and remained in distilled water at 37°C.

The remaining 160 specimens were divided into eight experimental groups, containing 20 specimens each, and received 35% hydrogen peroxide bleaching gel (Whiteness HP, FGM; batch number 110209;

Joinville, SC, Brazil) according to the manufacturer's specifications. A 2-mm layer of bleaching gel was applied to the enamel surface of the specimens. At 1-min intervals the gel was mixed on the surface. After 10 min, the specimens were washed with an air/water spray for 30 s and dried with blown air. The specimens received two new applications of bleaching gel following the same procedures described above. The experimental groups were divided according to the type of light activation, as follows:

- Group WL (without light): no light activation was used;
- Group HL (halogen lamp): for each application, the gel received five repetitive activations using a 1-min switch-on with a 1-min resting time (1 min on–1 min off) with a halogen light-curing unit (Curing Light XL 3000; 3M Dental Products, St. Paul, MN) at a power density of 700 mW/cm^2;
- Group EBLL (Easy Bleach/LED–laser): for each application, the gel received five activations following the same procedure described above with the hybrid device Easy Bleach (Clean Line, Taubaté, SP, Brazil) which has two blue light-emitting LEDs, each with a power of 500 mW, giving a total optical power of 1000 mW at a wavelength of 470 nm. This unit also contains an infrared diode laser with a power of 120 mW and at a wavelength of 795 nm (power density = 177 mW/cm^2);
- Group EBL (Easy Bleach/LED): for each application, the gel received five activations following the same procedures described above with the hybrid device Easy Bleach. However, the diode laser was turned off, with only the emission of blue LED light (power density = 158 mW/cm^2);
- Group QLL (Quasar/LED–laser): for each application, the gel received five activations following the same procedures described above with the hybrid device Quasar (Dentoflex, São Paulo, SP, Brazil) fitted with 19 blue light-emitting LEDs with a total optical power of 800 mW at a wavelength of 470 nm. This unit also contains an AsGaAl infrared diode laser with a power of 500 mW and at a wavelength of 830 nm (power density = 735 mW/cm^2);
- Group QL (Quasar/LED): for each application, the gel received five activations following the same procedures described above with the hybrid device Quasar. However, the diode laser was turned off, with only the emission of blue LED light (power density = 452 mW/cm^2);
- Group EGLL (Easy Green/LED–laser): for each application, the gel received five activations following the same procedures described above with the hybrid device Easy Green (Clean Line) which has two green light-emitting LEDs, each with a power of 300 mW, giving a total optical power of 600 mW at a wavelength of 530 nm. This unit also contains an infrared diode laser with a power of 120 mW and at a wavelength of 795 nm (power density = 114 mW/cm^2);
- Group EGL (Easy Green/LED): for each application, the gel received five activations following the same procedures described above with the hybrid device Easy Green. However, the diode laser was turned off, with only the emission of green light (power density = 95 mW/cm^2).

From the color measurements at baseline and after each time interval, the values of the changes in L* (ΔL; the lightness of the color), a*(Δa; the chromatic characteristics of the red–green axis), and b*(Δb; the chromatic characteristics of the yellow–blue axis) were calculated for each specimen. The total change in color or the variation in perception of the color of each tooth was calculated and designated ΔE, which refers to the color difference between the three periods. This parameter was calculated according to the following formula:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

Data were submitted to two-way ANOVA followed by the Tukey test at a 5% level of significance. For the control subgroups, changes in L*, a*, and b* at baseline and after 12 months were submitted to the paired *t*-test.

Results

Regarding the storage time factor, ANOVA showed a *P*-value of 0.0012 ($F = 6.94$), with seven degrees of freedom. ANOVA showed a *P*-value of 0.0000 ($F = 16.54$), with seven degrees of freedom, for the bleaching treatment factor. There were no significant variations in the values of ΔE for interaction between factors ($P = 0.9219$; $F = 0.52$; degrees of freedom = 7).

Table I shows the results of Tukey's test for the bleaching treatment factor. All groups showed significant differences from Group WL, except for Group EGL.

Table I. Results of Tukey's test for the bleaching treatment factor.

Group	Mean	Homogeneous sets[a]
QL	10.705	a
QLL	9.550	a
EBL	9.488	a b
EBLL	9.346	a b
H	8.535	a b c
EGLL	7.137	b c
EGL	5.315	c d
WL	4.209	d

[a]Means accompanied by the same letters presented no statistically significant differences.

Table II. Results of Tukey's test for the storage time factor.

Storage time	Mean	Homogeneous sets[a]
14 days	9.036	a
12 months	7.790	b
Baseline	7.279	b

[a]Means accompanied by the same letters presented no statistically significant differences.

Table II shows the results of Tukey's test for the storage time factor. A significant increase in ΔE was observed after 12 months of storage in distilled water when compared with values at baseline and after 14 days of storage.

Table III shows the results of L*, a*, and b* for the paired *t*-test at baseline and 12 months of storage for the negative and positive control subgroups. A significant variation in a* values after 12 months of storage can be observed for both subgroups.

Figure 1 shows the behavior of mean ΔE values for the different groups at different time periods.

Discussion

According to the results of this study, all groups that received light activation showed significantly higher ΔE values than the group that did not receive light application (Group WL), with the exception of Group EGL, which presented no significant differences in ΔE values compared with Group WL. This suggests that some light sources have a real effect on the bleaching process and this effect was significant for all groups, with the exception of Group EGL.

The null hypothesis that light has no effect on the intensity of tooth bleaching can be rejected, similar to the results observed by Li et al. [16], Tavares et al. [6], Luk et al. [7], Wetter et al. [17], and Wong et al. [8]. This result may be explained by the fact that when light is absorbed, it is converted into thermal energy (heat). This transformation is called the photo-thermal effect [11,18]. Previous authors stated that heating hydrogen peroxide can accelerate its decomposition reaction and the formation of its radical oxidants [1,18]. Furthermore, the increase in temperature promotes greater diffusion of hydrogen peroxide by enamel and dentin [19]. Wiegand et al. [20] showed that the change in color of externally bleached teeth is highly influenced by the change in color of dentin. Thus, faster penetration of hydrogen peroxide into dental hard tissue structure may be associated with the whitening effect of heat-activated bleaching methods [3]. Additionally, the action of light on the bleaching agents may be related to the occurrence of non-thermal effects on the chemical, which are known as photochemical effects, photolysis, or photodissociation. According to Crim [21], photons can produce an electronic excitement and/or vibration in the molecules, causing the disruption of certain chemical bonds, both intra- and intermolecularly. The change in vibrational state of the molecules requires the deposition of a relatively large amount of energy, which can be provided by high-energy photons. This can promote the decomposition of hydrogen peroxide [22].

When comparing the bleaching devices used in this study, it can be noted that some devices seemed to be more effective. It was observed that only Group EGL presented ΔE values close to those for Group WL, in which there was no application of light. This result may be due to the fact that the device used in Group EGL (Easy Green) showed the lowest power density (95 mw/cm^2), which may not have been sufficient to activate the hydrogen peroxide and increase its whitening efficacy when compared to the control group (Group WL).

To increase the interaction of visible light with the bleaching gel, manufacturers incorporate coloring agents or pigments into their products which have colors capable of promoting maximum absorption of this light and converting it into heat [23]. The coloring agents act as selectors or filters, absorbing one or more wavelengths and reflecting others. For this to occur, the pigment or coloring agent must have a specific color, known as the complementary color, which may be observed in the so-called chromatic circle, in which the complementary colors are in a diametrically opposed position [18,24]. For the gels with red coloring, the complementary color of the light to be used should be green. For the gels with orange coloring, the complementary color of the light to be used should be blue.

Although the bleaching gel used in this study contained red coloring agents that were capable of promoting maximum absorption of green light-emitting appliances, Groups EGL and EGLL, with green light devices, showed ΔE values significantly smaller when compared to Groups QL, QLL, EBL, and EBLL, with blue light devices. This result must

Table III. Comparison between control subgroups at baseline and after 12 months.

Subgroup	Parameter	Mean: Baseline	Mean: 12 months	*t*	*P*
Negative control	L*	80.233	82.383	−1.806	0.098
	a*	−1.066	−0.147	−3.707	0.003[a]
	b*	24.008	26.541	−1.856	0.0903
Positive control	L*	52.575	52.016	0.659	0.523
	a*	5.675	6.327	−2.338	0.039[a]
	b*	21.950	22.938	−1.724	0.112

[a]Significant differences.

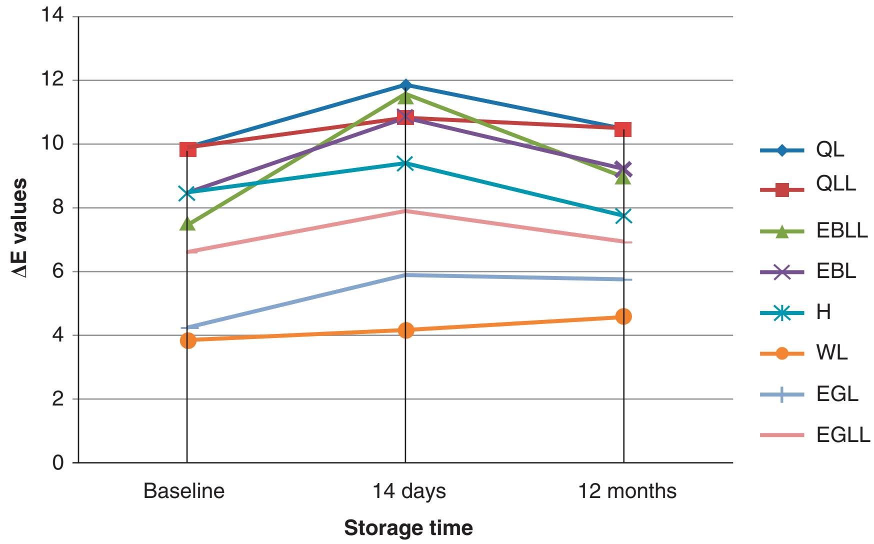

Figure 1. Mean ΔE values for all groups obtained at different storage times.

be due to the lower power density of the Easy Green device (95 mW/cm^2), even when combined with a laser (Group EGLL; 114 mW/cm^2), compared to groups QL, QLL, EBL, and EBLL, which showed a higher power density. There is a direct relation between power density and the heat emitted to the bleaching gel, which catalyzes the decomposition reaction of hydrogen peroxide and, consequently, the final result of tooth whitening [18].

It can also be observed that Group H, which used halogen lamps, showed no significant differences in ΔE values when compared with the radiation sources based on blue LED devices, with or without association with a laser. Nevertheless, with the light-curing units fitted with halogen lamps there is the risk of heating the teeth because of the nature of the light produced. Besides the emission of visible light, a large amount of infrared radiation is also generated. Although filters can minimize the arrival of these thermal waves to the tooth, they are not completely eliminated, and heating will always occur. Thus heating is promoted by both the infrared absorption and the colored gel [18].

The main energy source of the hybrid devices (LED/laser) catalyzing the bleaching reaction comes from LEDs emitting visible light, without emission of infrared radiation, reducing the possibility of pulpal damage due to excessive heating of the tooth. Torres et al. [18] indicate the use of LED devices due to their greater security in promoting selective heating during bleaching. Thus, light activation can be applied over longer periods without the risk of pulpal damage when compared with devices using halogen lamps.

With regard to the different times of color measurement, it was observed that 14 days of storage in distilled water resulted in a significant change in color of the specimens with regard to the ΔE values that were recorded at baseline. Thus the second null hypothesis that the ΔE values at the different times would not differ was rejected. This suggests that, even after the end of the bleaching session, the hydrogen peroxide and free radicals are trapped inside the tooth structure for some time, producing additional bleaching. Thus, in a clinical situation, the final color of teeth should not be assessed immediately after the bleaching procedure, but one should wait until the bleaching agent has acted fully and is released from the tooth structure.

Storage of specimens in distilled water for 12 months resulted in a significant decrease in ΔE values when compared with those at 14 days, which means that the teeth tended to undergo re-darkening. This is compatible with what is observed clinically, when patients complain of a regression in color and request further bleaching. However, it appears that the decline was not sufficient for the tooth to appear as dark as it was before the bleaching procedure. As the teeth were stored in water only, and not exposed to any coloring agent, this mild decline may be due to a re-connection of some of the chemical bonds that had been broken by the bleaching agents, as proposed by Lyons & Ng [25].

With regard to the variation in ΔE values after storage in the control subgroups, teeth in the negative (non-darkened, non-bleached) and positive (darkened, non-bleached) control subgroups did not show significant variation in L* and b* values between the readings at baseline and 12 months. However, a decrease in a* values was observed, showing a decrease in the chroma of the tooth structure, an effect precisely contrary to that which was observed in the bleached specimens. This may have been due to some interaction between the teeth and the water which, although it was regularly changed, may have allowed bacterial growth and perhaps its pH had changed, which may have interfered with the color.

As regards the association between the LED and diode laser, the results of this study showed no significant differences between all devices used. Thus, it can be considered that the combination of low-intensity diode lasers is generally ineffective as a bleaching gel activator. The diode lasers present in these devices emit infrared radiation. Although these waves have the ability to generate a certain rise in temperature of the bleaching gel and help to accelerate the hydrogen peroxide decomposition reaction [12], the main objective is to produce non-thermal, biomodulation, and therapeutic effects on dental pulp, in order to reduce cross-sensitivity and Post-operative sensitivity [12]. For this reason, the infrared laser diodes used were of low power, ≈100 to 500 mW. However, this function requires more scientific evidence.

Conclusions

Based on the results of this experiment, and considering the limitations of this *in-vitro* study, it was concluded that:

- Light activation of the bleaching gel tested with the high-intensity LED devices provided more intense bleaching than use of the bleaching gel without light activation;
- Storage of specimens in distilled water for 12 months resulted in a significant increase in ΔE values when compared to those at 14 days;
- The use of a low-intensity laser in association with LEDs did not significantly increase the bleaching effects compared to the use of LED devices.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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