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# Dental Bleaching Efficacy With Diode Laser and LED Irradiation: An In Vitro Study

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**Background and Objectives:** Bleaching techniques achieved significant advances with the use of coherent or incoherent radiation sources to activate the bleaching agents. This in vitro study compares the whitening efficacy of LED and diode laser irradiation using the two agents Opalescence X-tra and HP Whiteness.

**Study Design/Materials and Methods:** A total of 60 bovine incisors were randomly divided into six groups, three for each bleaching agent, receiving only agent, agent and LED (wavelength 470 nm), agent and 1.6 W diode laser (808 nm). The results of the irradiations were characterized using the *CIEL*a*b** system.

**Results:** Significant differences in the chroma value are obtained for the two whitening agents and for the different light sources. In terms of lightness, the association of Laser and Whiteness HP bleaching gel showed significantly better results than when the same agent was used alone or in combination with LED.

**Conclusions:** Best overall results are obtained with the Whiteness HP and Laser association. Lasers Surg. Med. 35:254–258, 2004. © 2004 Wiley-Liss, Inc.

**Key words:** tooth whitening; color measurement; tooth bleaching

## INTRODUCTION

A very frequent and common desire of patients is to have whiter teeth. Nowadays, aesthetic dentistry has turned its attention to this matter and a series of techniques and materials is constantly being developed for this purpose.

The first description of professional bleaching of stained teeth was accomplished by M'Quillen [1] in 1867. An electromagnetic irradiation source was used for the first time in 1937 to increase the bleaching efficacy, when Ames [2] applied a heat source to an oxidant agent (hydrogen peroxide at 35%). Finally, tooth whitening became largely used with the introduction of a whitening gel by Haywood and Heymann [3] in 1989, which enabled the use of bleaching agents at home originating the popular home bleaching technique [4–7].

There are several different types of irradiation sources in use to accelerate the in office bleaching procedure [8,9]. These techniques, using coherent [10,11] or incoherent [12] light sources, have the advantage of being quick and convenient. Generally, dental bleaching is accompanied by some sort of increased tooth or gingival sensitivity [13]. It has been shown that irradiation with visible and infrared light can provoke some beneficial effects on the sensitivity, due to photobiomodulation effects of certain wavelengths [14]. Among the newest irradiation devices are light emitting diodes (LEDs) [15] and diode lasers. Both are extremely compact devices when compared to plasma arc lamps, very efficient and therefore, need no moving, noisy parts like ventilators or refrigeration pumps [16]. The differences are that diode lasers emit coherent, well-collimated light whereas LEDs are cheaper but much more difficult to collimate usually presenting smaller output power.

Human evaluation of dental tooth shade is prone to suffer influence from environmental and physical variables like ambient light, differences in the number of cones and rods within the retina of the eye and many others [17]. For this reason, a significant goal of color vision research has been the specification of human color response in a way that it can be readily detected by electronic color measurement devices [18]. A recent milestone in this effort is the *CIEL*a*b** color system [19] allowing the difference between colors to be calculated as the Euclidean distance between their coordinates in three-dimensional *CIEL*a*b** space. The three last letters in the name *CIEL*a*b** refer to the three perpendicular directions in color space: $a^*$ is the red-green contrast (positive $a$ values correspond to a carmine red and negative $a$ values are its opposite, blue green); $b^*$ is the yellow-blue contrast (positive $b$ values correspond to a light yellow and negative $b$ values are deep blue). $L^*$ corresponds to the luminosity dimension or whiteness, ranging from 0 (pure black) to 100 (reference white) and it is proportional to the luminance. The chroma $C^*$ or color saturation, which means the distance from the gray axis ($L^*$) in *CIEL*a*b** space, represents the change from unsaturated (dull) to saturated

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(bright) colors. The larger $C^*$, the more intense (saturated) is the color. Therefore, the two attributes that define the perceived increase in brightness achieved by the bleaching procedure, are the change in whiteness ($\Delta L^*$) and the change in chroma ($\Delta C^*$).

To the human eye, color intensity (chroma) seems like light intensity (whiteness). This is especially true for the yellow color, which reaches its strongest saturation at high whiteness values, as represented in the Munsell color system [20]. Color samples in the Munsell system are perceptually equidistant on the dimensions of value (the luminosity dimension), chroma and hue (the principle of equal perceived distance applies within each dimension of the model separately, not across dimensions). The Munsell system is based upon a cylindrical coordinate system, whereas the *CIEL*a*b** system is based on a rectilinear cartesian coordinate system that permits to describe and algebraically manipulate color differences between coordinates in color space.

This study analyzes, through spectrophotometric comparison, the efficacy of diode laser and LED irradiation, using the bleaching agents Opalescence X-tra and HP Whiteness.

## MATERIALS AND METHODS

The two bleaching agents Whiteness HP (FGM Produtos Odontológicos, Joinville, Brazil) and Opalescence X-tra (Ultradent Products, Inc., UT) contain both 35% of hydrogen peroxide and have very similar consistency. Whiteness HP has a carmine red color, which rapidly fades away after application whereas Opalescence X-tra comes with a bright red color due to its carotene content. Both agents are also indicated for use without activation by a special light source.

The model Laserlight (Kondortech Equipamentos Ltda., São Carlos-SP, Brazil) has a total of eight LEDs inside a handpiece presenting a 15-mm-diameter circular aperture and 8° divergence angle. This device has a luminous intensity of 32 cd at the blue wavelength of 470 nm and the only possible adjustment is the irradiation time. The diode laser (GaAlAs diode, Lasering L-808 model, New Image do Brasil Lta., São Paulo, Brazil) operates at 808 nm with up to 15 W of output power. The diode laser beam is delivered through an optical fiber coupled to a 6-mm-aperture handpiece with 76 mrad of divergence angle.

A total of 60 bovine incisors had their enamel surface cleaned with Robinson brush (8040 Viking model, KG Sorensen, São Paulo, Brazil) and pumice (SS White, Artigos Odontológicos Ltda., Brazil). The roots were separated using a diamond saw (model 15 HC, Bühler), the pulpal tissue was removed and the dentin sealed off with self-curing epoxy. The teeth were then stored in distilled water under refrigeration at 8°C in order to keep them hydrated.

All teeth had their $L^*a^*b^*$ values measured for the first time with the spectrophotometer (model Cintra 10, GBC Scientific Equipment, Australia) and were subsequently immersed into a staining solution made of tobacco, black tea, coffee, Coca-Cola, and red wine for 7 days at a temperature of 37°C. The receptacle containing the staining liquid was stirred once every day to avoid decantation of the staining products. After this period the teeth were rinsed for the second time and the *CIEL*a*b** values were measured again.

**TABLE 1. Group Divisions**

| Agent/light source | Control | LED | Laser |
|---|---|---|---|
| Opalescence X-tra | Group G1 | Group G3 | Group G5 |
| Whiteness HP | Group G2 | Group G4 | Group G6 |

The teeth were divided into three groups according to control, LED, and diode laser irradiation. Half of the teeth in each group received Opalescence X-tra as the bleaching agent, the other have received Whiteness HP, with a total of six groups containing ten specimens each ($n = 10$) according to Table 1.

An approximately 2 mm thick layer of the bleaching agents was applied and kept for 10 minutes on the control group teeth surfaces, G1 and G2, under normal laboratory illumination. Groups G3 and G4 received the bleaching agents as in Table 1 and were subsequently irradiated for 3 minutes with the LED kept at a distance of 5 mm.

Groups G5 and G6 received a 2 mm layer of the bleaching agents and were immediately irradiated with 1.6 W of output power from the diode laser during 30 seconds, with an energy density of 21.3 J/cm$^2$. The bleaching agents remained on the teeth surfaces for another 7 minutes and irradiated again for 30 seconds. Following this, the bleaching agents were washed off and a new layer was applied and irradiated for 30 seconds using the same procedure as in the first activation. After this second irradiation, the agents were immediately washed off and the teeth rinsed.

Groups G3 to G6 were irradiated with the hand piece perpendicular to the enamel surface, at a distance of 2 mm from the bleaching agent. The surface was irradiated in a uniform, sweeping, and scanning motion, covering an area on the buccal surface of approximately 2.25 cm$^2$. Due to the very small divergence angles of these equipments a large positioning error of 50% would result in a difference in energy density of only 4 and 5% for the LED and laser, respectively.

The $L^*a^*b^*$ values were measured for the last time and then the differences between the three *CIEL*a*b** measurements were evaluated.

In order to verify if the two factors bleaching agent and light source affect significantly the mean values, an analysis for multiple comparisons using the Fisher's least significant difference (LSD) method [21] was applied with a 95% confidence interval ($P<0.05$).

## RESULTS

Figure 1 shows the measured $L^*a^*b^*$ values, where the mean value of all the samples is stated before and after immersion in the staining solution as well as the mean values after the individual treatments from G1 to G6.

The lightness $L^*$ values dropped significantly from the first measurement to the measurement after the staining procedure and did not recover to the initial values within

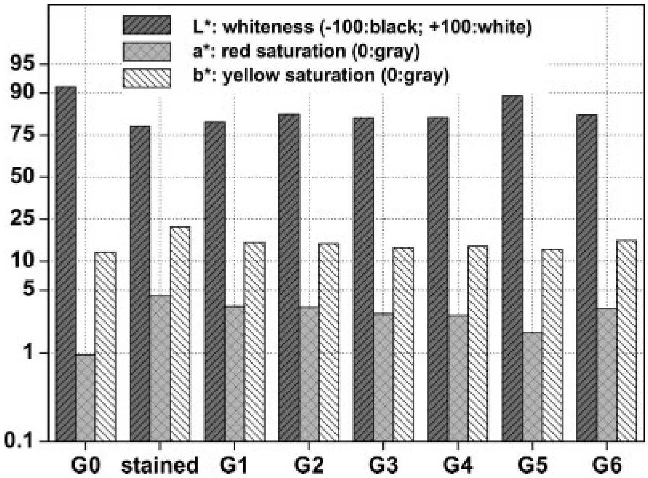


Fig. 1. $L^*a^*b^*$ values of the samples before staining (G0), after staining and after the treatments (G1–G6).

none of the six procedures from G1 to G6. The same happened with the $a^*$ and $b^*$ values. All teeth showed a predominantly yellow hue, being the $b^*$ value between 12 and 21, and only a slight contribution from the transverse color dimension red (positive $a^*$ value), being this value between 0.9 and 4.2.

The chroma value, which is proportional to the saturation of the color, was calculated by the formula $C^* = (a^* + b^*)^{1/2}$ [19]. The mean values of $L^*$ and $C^*$ and their standard deviations are shown in Tables 2 and 3. In order to have a more accurate analysis of the results they were separated according to the bleaching agent and light source. The differences in $L^*$ and $C^*$ introduced by the respective treatment procedures from groups G1 to G6 were also analyzed. These values correspond to the differences of the last two columns in Tables 2 and 3, respectively and the results are shown in Figures 2 and 3. These are the main results and they will be discussed in detail below. It should be noted that the standard deviations in these figures are large because they are calculated from the mean values of Tables 2 and 3.

The lightness increase of the association Whiteness HP and laser (G6) is significantly higher than for LED (G4) or control (G2) (Fig. 2). No significant difference exists between this association (G6) and the three groups using Opalescence X-tra (G1, G3, and G5). There is no significant difference in between the groups from G1 to G5. Furthermore, there exists an apparent trend of the LED interacting better with Opalescence X-tra (group G3) than the control (G1) and the diode laser (G5). This situation is reversed with the Whiteness HP bleaching agent.

Figure 3 clearly shows that the three groups where the Whiteness HP bleaching agent was applied (G2, G4, and G6) had their mean chroma values less decreased when compared to Opalescence X-tra. The mean chroma decrease of Whiteness HP is significantly smaller than the one from Opalescence X-tra.

The factor "light source" is also significant when it comes to the chroma (Fig. 3). The mean change in chroma for both combinations using laser (groups G5 and G6) was significantly smaller than for all the other light sources. Group G6 showed the smallest chroma change (although not statistically different from G5) and therefore, moved less into the direction of the achromatic gray axis ($L^*$ axis) of the *CIEL*$^*a^*b^*$* color sphere.

## DISCUSSION

Few investigations have been published analyzing the efficacy of LED and diode laser regarding the bleaching procedure. White et al. [22] compared in a similar research bovine teeth samples treated with three different bleaching agents and plasma arc curing light or diode laser at three different output powers. Their research did not determine statistical superiority of any agent/light combination. All combinations achieved higher lightness values and in terms of hue, the teeth experienced a slight green shift during the bleaching procedure when analyzed through the spectrophotometer. Gerlach and Zhou [23] reported an improvement of $\Delta L^*$ of two units with a whitening strip product. Sulieman et al. [24] found an average change in $\Delta L^*$ of around 20 units when investigating various bleaching regimes.

The spectrophotometer analyzes the samples under only one light source. By doing so, it aims to reduce the possible reading bias, which does not occur in the dental office where several types of light sources are found. It is important to remember that the values obtained from the spectrophotometer have as a reference the light of the day and this is not always recognized by the human eye mainly if the metamerism of the object is to be considered.

Regarding the $L^*a^*b^*$ values obtained in this study, high $L^*$ values correspond to a higher luminosity being the lowest ones associated with less clarity, which is not expected after the dental bleaching procedure. Regarding the chroma, higher $C^*$ values correspond to a higher

**TABLE 2. Mean Values and Standard Deviation of $L^*$**

| Agent | Irradiation | Initial | Stained | Final |
|---|---|---|---|---|
| Opalescence X-tra | Control | $90.8 \pm 1.5$ | $76.1 \pm 6.9$ | $80.9 \pm 6.5$ |
| | LED | $91.3 \pm 3.1$ | $78.7 \pm 8.1$ | $82.6 \pm 8.4$ |
| | Laser | $90.9 \pm 1.9$ | $85.0 \pm 2.9$ | $89.3 \pm 3.7$ |
| Whiteness HP | Control | $92.9 \pm 1.9$ | $79.9 \pm 6.2$ | $83.7 \pm 6.6$ |
| | LED | $90.6 \pm 3.0$ | $79.4 \pm 5.7$ | $82.7 \pm 5.2$ |
| | Laser | $89.7 \pm 2.6$ | $77.6 \pm 6.5$ | $84.5 \pm 5.5$ |

**TABLE 3. Mean Values and Standard Deviation of $C^*$**

| Agent | Irradiation | Initial | Stained | Final |
|---|---|---|---|---|
| Opalescence X-tra | Control | $11.9 \pm 1.2$ | $24.7 \pm 5.3$ | $15.8 \pm 4.4$ |
| | LED | $11.6 \pm 2.1$ | $21.5 \pm 4.6$ | $14.0 \pm 5.3$ |
| | Laser | $13.7 \pm 2.1$ | $19.7 \pm 3.1$ | $13.5 \pm 2.2$ |
| Whiteness HP | Control | $11.5 \pm 1.5$ | $21.9 \pm 4.3$ | $15.3 \pm 4.3$ |
| | LED | $13.7 \pm 2.1$ | $22.0 \pm 4.9$ | $14.3 \pm 3.1$ |
| | Laser | $14.6 \pm 2.5$ | $21.7 \pm 3.0$ | $16.4 \pm 2.7$ |

saturation, being the lowest values (less saturation) next to the achromatic gray color ($C^* = 0$). Because the chroma value is linked to the luminosity value $L^*$ by means of the color sphere, the higher the luminosity the smaller the maximum possible saturation. For the highest luminosity value there is no hue and $C^*$ has to be zero (completely white teeth, top of the color sphere, $L^* = 100$). For values of $L^*$ bigger than 95, the only hue that can be strongly saturated is yellow [20].

Gibb et al. showed [25] in a study involving 473 subjects from six different US sites, that the mean $b^*$ value of the patients at these sites is 17.7 and the corresponding mean $L^*$ value is 74. Hasegawa et al. [26] performed a study of the natural tooth color on 87 subjects in Japan and measured a mean $L^*$ value of 73 and mean $b^*$ value of 16.5. At these $L^*$ values strong saturation of almost all hues is possible and, therefore, the chroma value is an issue. According to Gerlach et al. [27], $\Delta C$ is the primary response variable because it is a directional measurement having the most perceptual relevance. Through the $\Delta C^*$ values it is possible to have a more accurate analysis when studying human teeth where the yellow color predominates through transparency of dentin in normal conditions. Also, the higher the saturation, the brighter the teeth appear to the human eye, whereas grayish colored teeth ($C^* = 0$) are mostly unacceptable to the patients [28]. Joiner [18] summarized seven studies from five different countries that measured the natural tooth color in *CIEL*a*b** color space. The four studies that measured low mean $L^*$ values of less than 52 also show small mean $C^*$ values of less than 3.1 whereas the remaining three studies that produced whiteness values higher than 67 also show stronger color saturation and mean $C^*$ values higher than 12.8. It remains to say that the satisfaction of personal tooth color is related to culture and individual preferences, as shown by Odioso et al. [28]. This study shows that the patients may seek to have whiter teeth within their peer group and not the whitest teeth possible.

The teeth bleached by the LEDs tended more to gray because they suffered a major chroma reduction. The ones, which were laser irradiated had a better result regarding the chroma which meant they tended less to gray.

Another important factor to be taken into account is the irradiation time of both light sources. The LED was used for 3 minutes and the laser for 30 seconds. Whiteness HP is a bleaching agent which original color gradually fades in about 2 minutes. Therefore, the ideal photochemical interaction is lost when the LED is used due to the relatively long irradiation time of 3 minutes. For this situation, the laser irradiation is more advisable. On the other hand, the Opalesce X-tra absorbs predominantly the blue (LED), therefore, it reacts better with this light source and according to the results achieved in this study there was more regularity on the bleaching $L^*a^*b^*$ values.

This research produced significant differences between the results of the agent/light source associations. Regarding the lightness $L^*$ and the chroma $C^*$ values, the best

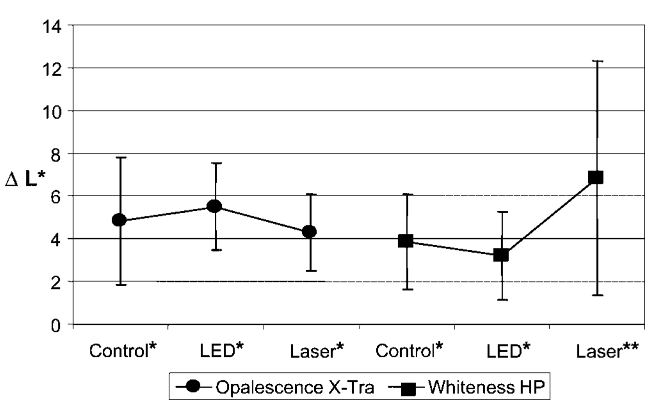


Fig. 2. Mean values of $\Delta L^*$ and standard deviations. Statistically significant differences exist between groups of the same bleaching agent marked with (*) and (**). No significant differences were found for comparisons between groups treated with Opalescence and Whiteness.

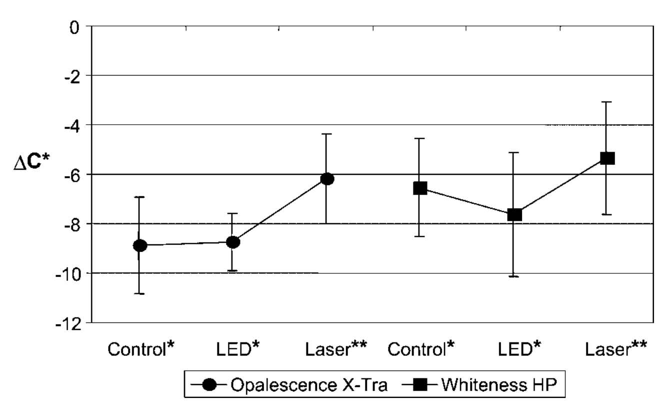


Fig. 3. Mean values of $\Delta C^*$ and standard deviations. Statistically significant differences exist between groups of the same bleaching agent marked with (*) and (**). Additionally, the mean chroma decrease of Whiteness HP is significantly smaller than the one of Opalescence X-tra.

results were obtained with the Whiteness HP bleaching gel and diode laser association. The Whiteness HP bleaching agent always showed a more efficient interaction with the laser whereas the Opalescence X-tra interacted better with the LED. This latter result is in part expected because of the carotene, the pigment contained in Opalescence X-tra, which has its absorption peak at the emission wavelength of the LED and, therefore, efficiently absorbs the LED radiation.

## CONCLUSIONS

This is to our knowledge the first time that the light sources Laser and LED are compared regarding their whitening capability when applied to different bleaching agents. Both light sources achieved the dental bleaching result. The laser showed to be more effective than the LED both in chroma and luminosity when associated with the Whiteness HP bleaching agent. The LED achieved better results than the laser regarding the luminosity when associated with the Opalescence X-tra bleaching agent. This paper represents the initial study where LED and diode laser were compared. Further studies are necessary and are being conducted in order to confirm these results.

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