Effects of KTP Laser Irradiation, Diode Laser, and LED on Tooth Bleaching: A Comparative Study


ABSTRACT

Objective: This in vitro study examines the whitening efficacy of a light-emitting diode (LED), a diode laser, and a KTP laser irradiation in dental bleaching by analyzing the change in color achieved from the treatment, the temperature increase induced in the pulpal cavity, as well as enamel microhardness measurement after treatment. Background Data: Bleaching techniques achieved significant advances with the use of coherent or incoherent radiation sources to activate the bleaching agents. Methods: A hydrogen peroxide bleaching agent, Hi-Lite, was stimulated with an LED, a 980-nm diode laser at 0.8 W, or a 532-nm KTP laser at 1.0 W for 30 sec on 64 extracted human incisors. During irradiation, the temperature in the pulpal cavity was monitored. The color change was evaluated using the CIE L*a*b* color space measurement system, and Vikers enamel microhardness was tested after treatment. Results: A mean total color difference value (ΔE*) greater than 5.0 was obtained in each group. KTP-laser–induced bleaching gave a significantly higher ΔL* (8.35) after treatment (p < 0.01). Neither LED nor the two lasers produced significant differences in the enamel microhardness after treatment (p > 0.01). Mean maximal pulpal temperature rise was 2.95°C for LED, 3.76°C for KTP laser, and 7.72°C for diode laser, respectively. Conclusion: The results of this study suggest that KTP laser is effective at providing brighter teeth. According to the conditions used in this study, the LED and KTP laser induced a safer pulpal temperature increase when assisted with Hi-Lite bleaching gel.

INTRODUCTION

TOOTH SHADE, which is the result of diffuse reflectance from the dentin through the translucent enamel layer, is believed to be one of the most important factors in patients’ perception of dental attractiveness.1,2 Nowadays, vital tooth bleaching has become a popular aesthetic dental treatment, and techniques and materials are constantly being developed for this purpose. Professional bleaching of stained teeth was first described by M’Quillen in 1867.3 Electromagnetic irradiation was used for the first time in 1937 to increase the bleaching efficacy; a heat source was applied to an oxidant agent (hydrogen peroxide at 35%).4 By the 1990s, a whitening gel was introduced that enabled the use of bleaching agents at home, originating the popular home bleaching technique.5–8

Although home bleaching is effective and has become widely accepted during the past 10 years, the advantages of an in-office whitening procedure over a home bleaching technique are obvious. These include control by the dentist, avoidance of soft tissue exposure and material ingestion, reduced total treatment time, and great potential for immediate results to patients’ satisfaction and compliance.9 Several different types of irradiation sources have been used to accelerate the in-office bleaching procedure10,11 and are claimed to reduce the total in-office bleaching time. Among them, laser tooth bleaching officially started in 1996, with the approval of the argon laser (480 nm) and the CO2 laser (10.6 μm).12 Generally, dental bleaching is accompanied by increased tooth or gingival sensitivity, and laser irradiation appeared to have a palliative effect on sensitivity.13 However, laser irradiation would also increase
the intrapulpal temperature, and this issue of pulpal health needs to be considered before using laser bleaching on vital teeth.\textsuperscript{14}

Recently, a new KTP laser device was invented for in-office bleaching. Its unique optical and chemical interactions make photochemical bleaching possible by promoting oxidation events in a controlled manner.\textsuperscript{15} Moreover, a case report has shown that the application of this system resulted in more powerful whitening.\textsuperscript{16} However, our literature review revealed that no systematic comparative investigation has been performed on this new laser.

The purposes of this in vitro study were to evaluate the effects of a KTP laser, a diode laser, and a light-emitting diode (LED) on tooth whitening, to investigate the intrapulpal temperature rise induced by these light sources, and to analyze any changes in tooth surface microhardness after these procedures.

**METHODS**

**Sample preparation**

A total of 68 human extracted maxillary incisors with intact crowns were used. After extraction, all soft tissues and debris were removed with scalers. None of the teeth had any caries, restorations, or enamel cracks. The teeth were stored in 0.2% thymol solution after extraction. The labial surfaces were cleaned with fine pumice slurry using a slow handpiece recommendation. The laser fiber tip/LED light was held 1 cm away, perpendicular to the enamel surface, and the beam was used to cover the enamel surface in an area of approximately 2.25 cm\(^2\) on the labial surface. The bleaching agent remained on the tooth surface for 7.5 min. All teeth were thoroughly washed with water and gently blotted dried, and thereby one pass of bleaching was completed. For each tooth in groups 1–4, the bleaching agent was kept on the enamel surface for 7.5 min. All teeth were stored in 0.2% thymol solution after extraction. The labial surfaces were cleaned with fine pumice slurry using a slow handpiece equipped with a disposable prophylaxis cup.

**Bleaching method**

A bleaching agent containing 35% H\(_2\)O\(_2\) (Hi-Lite; Shofu, Kyoto, Japan) was used in the present study, activated with three different light systems: KTP laser (SMARTLITE D; Deka, Frenze, Italy) operated at 532 nm with output at 1.0 W; diode laser (Prototype; MANI, Inc., Takanezawa, Japan) with a wavelength of 980 nm and output at 1.0 W; Elipar Freelight (3M, St. Paul, MN) with an LED of blue color light and a main wavelength of 470 nm. In all laser devices, the laser beam was delivered through an optic fiber to an aperture handpiece.

**Colorimetric measurements**

Forty teeth were used for evaluation of the color variable before and after bleaching. The apical foramen of each tooth was sealed with wax, and its exposed dentin and cementum were coated by two layers of nail varnish. The teeth were randomly divided into four groups, and each group contained 10 teeth (Table 1). A positioning appliance and whitening tray were fabricated, using a direct method, for each tooth with ethylene vinyl acetate. Each labial crown surface was divided into equal halves with calipers, and the midpoint of each tooth was calculated. Guidance holes with 3-mm-wide apertures were drilled into the midpoint of the test surface at approximately the same angle. This facilitated the construction of a positioning appliance and a whitening tray for each tooth to allow repeatable measurements of the same test area. It also held the test surface at the same angle to the measuring head of the colorimeter during each measurement. A colorimeter (Minolta CR-410; Konica Minolta Co., Tokyo, Japan) was used to record color variables \(L^*\), \(a^*\), \(b^*\) according to the CIE \(L^*a^*b^*\) (Commission Internationale de l’ Eclairage \(L^*, a^*, b^*\) system. The teeth were totally immersed in normal saline overnight at 37°C, rinsed with water, and dried, and then the color was measured with colorimeter (baseline). Next, bleaching gel was placed to a thickness of approximately 1 mm on the enamel surface of the experimental tooth. For the teeth in Groups 1–3, once the bleaching gel had been placed, KTP laser irradiation (continuous mode, output power 1.0 W, energy density 13.33 J/cm\(^2\)), diode laser irradiation (continuous mode, output power 1.0 W, energy density 13.33 J/cm\(^2\)), or LED irradiation (light intensity 12.6 J/cm\(^2\)) was performed for 30 sec each. Each parameter used in this study was based on the manufacturer’s recommendation. The color fiber tip/LED light was held 1 cm away, perpendicular to the enamel surface, and the beam was used to cover the enamel surface in an area of approximately 2.25 cm\(^2\) on the labial surface. The bleaching agent remained on the tooth surface for another 7 min after irradiation. For the teeth in group 4, the bleaching agent was kept on the enamel surface for 7.5 min. All teeth were stored in 0.2% thymol solution after extraction. The labial surfaces were cleaned with fine pumice slurry using a slow handpiece equipped with a disposable prophylaxis cup.

**TABLE 1. LIGHT SOURCES AND BLEACHING AGENT IN GROUP DIVISIONS**

<table>
<thead>
<tr>
<th>Groups</th>
<th>(n)</th>
<th>Bleaching agent (Hi-Lite)</th>
<th>Light sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td></td>
<td>KTP laser</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td></td>
<td>Diode laser</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td></td>
<td>LED</td>
</tr>
<tr>
<td>4 (control)</td>
<td>10</td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

where \(\Delta L^*\) = \(L^*\) (post) – \(L^*\) (0)

\(\Delta a^* = a^*\) (post) – \(a^*\) (0)

\(\Delta b^* = b^*\) (post) – \(b^*\) (0)

where post is the value post-treatment and 0 is the value at baseline. Total color difference values \(\Delta E^{*ab}\) between baseline and subsequent measurements were expressed as a distance between two points in space and calculated according to the following formula:

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

**Microhardness test**

After color measurements, 10 teeth in each group of colorimetric measurements and another 10 teeth that did not receive any bleaching (as a negative control group) were prepared. The specimens in the negative control group were treated in the
KTP Laser, Diode Laser, and LED on Tooth Bleaching

same manner as experimental groups in terms of rinsing and drying. Instead of a bleaching agent, drops of distilled water were applied to the enamel surface. Specimens were mounted and cut with an Isomet saw (Buchler, IL), which gave approximately 4-mm-thick mesial-distal cross-sections from the middle third of the teeth. The cut surfaces were polished with 3, 1, and 0.25 μm diamond suspensions (Sumitomo 3M Co., Tokyo, Japan). The polished enamel surface was indented five times per sample with a square-based pyramidal Vickers indenter under a load of 700 g for 15 sec, using a Microhardness Tester (HM-112; Mitutoyo Co., Kawasaki, Japan). The mean Vickers hardness (VH) value for each group was determined.

Temperature measurements

Eighteen teeth were used for measurement of intrapulpal temperature rise during laser irradiation. Before testing, the teeth were rinsed in normal saline for 1 h. They were randomly distributed into three groups (group a, KTP laser irradiation; group b, diode laser irradiation; and group c, LED irradiation), and each group contained six teeth. The root of each tooth was cut approximately 2–3 mm apically, and the apical foramen of the root canal was enlarged with a no. 5 round bur using a low-speed handpiece. A thin K-type thermocouple (diameter 0.5 mm) was introduced into the pulp chamber through the opened apical foramen until contact with the wall opposite to the labial surface to be bleached, which was verified later by radiography. The foramen was then sealed with wax, and the bleaching gel was placed in an approximately 1-mm-thickness on the enamel surface of the tooth, and laser/LED irradiation was applied. During exposure, temperature changes in the pulp chamber were measured by a thermometer (PTC-201; Unique Medical Co. Ltd., Tokyo, Japan), which was connected to the thermocouples inside the pulp, and were recorded by a computer. The recording precision was 0.1°C. The ambient temperature was kept at 25°C, and the relative humidity was 65%.

Statistical analysis

Statistical analysis was performed using the Kruskal-Wallis test, and significance was set at a probability value of less than 0.01.

RESULTS

Color change values after different treatments are shown in Table 2. A mean total color difference value (ΔE*) greater than 5.0 was obtained in each group. KTP laser-induced bleaching (group 1) gave a significantly higher ΔL* after treatment, whereas bleaching agents used with diode laser (group 2) or LED (Group 3) failed to show any significant color changes compared with the control.

The mean enamel microhardness values after treatment are shown in Figure 1. Statistical analysis revealed no significant differences among the five groups (p > 0.01).

Maximal pulpal temperature rises during bleaching are given in Table 3. Diode laser induced a significantly higher temperature rise than the other two devices (p < 0.01). LED produced the lowest pulpal temperature rise; however, there was no significant difference between the LED group and KTP laser group (p > 0.01).

<table>
<thead>
<tr>
<th>Groups</th>
<th>ΔL*</th>
<th>Δa*</th>
<th>Δb*</th>
<th>ΔE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.35 (2.72)*</td>
<td>0.87 (0.34)</td>
<td>–3.10 (1.46)</td>
<td>8.79 (3.05)</td>
</tr>
<tr>
<td>2</td>
<td>4.96 (1.98)</td>
<td>1.37 (0.56)</td>
<td>–2.38 (1.12)</td>
<td>5.74 (2.04)</td>
</tr>
<tr>
<td>3</td>
<td>4.73 (1.87)</td>
<td>1.74 (0.69)</td>
<td>–3.61 (1.29)</td>
<td>6.41 (2.47)</td>
</tr>
<tr>
<td>4</td>
<td>4.25 (1.66)</td>
<td>1.59 (0.72)</td>
<td>–2.63 (1.03)</td>
<td>5.22 (2.20)</td>
</tr>
</tbody>
</table>

*Significant difference (p < 0.01).

Values show the mean and standard deviation. ΔL* = L* (post) – L* (0), Δa* = a* (post) – a* (0), Δb* = b* (post) – b* (0), where post is the value post-treatment and 0 is the value at baseline. Total color difference values (ΔE*ab) between baseline and subsequent measurements were calculated according to the following formula: ΔE*ab = [(ΔL*)2 + (Δa*)2 + (Δb*)2]1/2.

<table>
<thead>
<tr>
<th>Light sources</th>
<th>Maximal temperature rises (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>KTP laser</td>
</tr>
<tr>
<td>b</td>
<td>Diode laser</td>
</tr>
<tr>
<td>c</td>
<td>LED</td>
</tr>
</tbody>
</table>

*Significant difference (p < 0.01).


DISCUSSION

To evaluate the effectiveness of different bleaching treatments, a number of laboratory models have been developed in which extracted teeth are stained in tea, coffee, or chlorhexidine. However, each of these models has limitations because discoloration of teeth is caused by many chromogens, except when dentin becomes exposed. Therefore, in the present study, the specimens were prepared without any artificial stain, and only polished to eliminate stain in the pellicle. This was believed to mimic the clinical situation of teeth more effectively.

Aqueous hydrogen peroxide has been used clinically for many years at levels of 30–35% to lighten teeth. The whitening mode of hydrogen peroxide involves the diffusion of peroxide through enamel, causing bleaching of the pigments found in the enamel–dentin junction and dentin areas. This makes teeth appear whiter and less yellowish. Energy sources—such as heat, halogen, LED, diode laser, and other lasers—were believed to be capable of catalyzing hydrogen peroxide decomposition and therefore were used to speed tooth bleaching.

In the CIE L*a*b* color order system, the L* axis describes the value. High L* values are obtained from bright or white samples. The a* axis measures the hue-chroma in the red-green direction. The b* axis represents the hue-chroma in the blue-yellow direction. Total color difference (ΔE*a*b*) is calculated mathematically, and its value has been correlated with limits of human detection whereby 50% of the population can perceive a color difference in a unit greater than one. Other studies have reported that color difference values less than 3.3 can be considered clinically insignificant. In the present study, a mean total color difference value greater than 3.3 was obtained in each group. The L*a*b* value analysis showed that in all the four groups the specimens increased in whiteness and decreased in yellow shade. This indicated that successful bleaching was achieved in all four groups. Specimens in the KTP laser group gave the greatest mean total color difference value of 8.79, but no statistically significant difference among the mean total color difference values in the four groups was found. However, regarding the L* values, the better whitening effect of KTP laser–induced bleaching has clearly been demonstrated (Table 2), giving a significant increase in brightness (ΔL*) compared with other groups. This is of great value in clinical tooth whitening treatment. Wetter et al. reported that an 808-nm diode laser associated with bleaching gel showed significantly better result than both LED associated with bleaching gel and bleaching gel only. Nevertheless, the diode laser failed to show a similar effect in the present study. Possible reasons could be different wavelength, output, irradiation time, and bleaching agent.

One of the possible side effects of bleaching products reported for many years is the weakening of enamel structure by oxidation of organic or inorganic elements. Changes in microhardness are related to a loss or gain of mineral (demineralization or remineralization) of dental structure. It has been shown that the microhardness test is suitable for determining small changes in surface that demonstrated the effect of bleaching products on enamel. This study showed no significant difference in the VH values between the control and four experimental groups. This was in agreement with previous studies.

When lasers are used in vital tooth bleaching, the adverse thermal damage to pulp must be considered. This in vitro study measured the temperature rises caused by LED and two different lasers. Under the conditions of the present study, the highest temperature rise was recorded when using the diode laser for 30 sec. The temperature rise during activation of bleaching agent was lower with LED than with KTP laser. This result was in agreement with that reported in a previous study, in which LED produced the least thermal changes during the bleaching process. Zach and Cohen reported irreversible pulp damage in 15% of the observed teeth for an intrapulpal temperature rise of 5.5°C, 60% for a temperature rise of 11°C, and 100% for temperature rise of 16.6°C. Although their experimental conditions were different from the present study, their results can be considered as a baseline for potential histopathological changes in pulp tissue when the intrapulpal temperature elevation exceeds 5.5°C. On the other hand, the total duration of temperature rise and storage of harmful heat is also of importance. Eriksson et al. demonstrated that 42°C was a critical temperature when maintained for 1 minute, whilst Reingewirtz et al. showed that energy dissipation is rapid and occurs within 10 sec. Kreisler et al. reported that diode laser irradiation on root surface may impair pulp vitality, and a power output of 1.0 W and exposure time of 10 sec must not be exceeded to ensure safe clinical application. In the present study, the diode laser was used at a power output of 1.0 W for 30 sec according to the manufacturer’s instructions, and it resulted in a temperature rise of 7.7°C, whereas the temperature rise recorded was 3.8°C for KTP laser, and 2.9°C for LED. Regarding these values, the maximal intrapulpal temperature rise detected for LED and KTP laser under the present conditions were safe and harmless to the pulp, whereas application of the diode laser was viewed as critical during bleaching treatment.

Successful vital bleaching requires good whitening efficacy without pulp damage. In the present study, KTP laser demonstrated potential advantages when combined with bleaching agent. Theoretically, the intrapulpal temperature increases associated with laser application could be weakened by reducing the duration of laser irradiation, increasing the thickness of applied bleaching agent, or increasing the absorption of laser by the bleaching agent, thereby decreasing the transmission of laser energy through the tooth, which makes laser-assisted bleaching safer. Further studies are needed to determine the most favorable protocol and parameters for this promising KTP laser in dental bleaching.

CONCLUSION

The results of the present study indicated that successful bleaching was achieved with each of three light sources—KTP laser, diode laser, and LED—when associated with Hi-Lite; however, the 532-nm KTP laser was capable of producing significantly more whitening than LED or diode laser. None of the three light sources employed in this study had a detrimental effect on enamel hardness. During activation of bleaching material, diode laser caused significantly higher intrapulpal temperature rise, which was a disadvantage, whereas KTP laser and LED showed pulp-reserving results under the conditions tested. KTP laser is potentially a valid and safe tool for laser-assisted tooth bleaching in the clinic.
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REFERENCES


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