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Original Article

Influence of Different Light-Activated Bleaching Gels on Pulp Chamber Temperature: An In Vitro Study

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Abstract

Background: Significant advances in in-office bleaching treatments have been made by introducing some types of light sources. Halogen lights, LEDs, and diode lasers are the most popular devices used for in-office bleaching. There is a risk that bleaching-activating light sources might increase temperature and have side effects on the dental pulp. This study evaluated the effect of different light-activated bleaching gels on pulp chamber temperature.

Methods: In this experimental study, 36 bovine incisor teeth were selected for investigation. The samples were divided into three groups, including Opalescence Xtra Boost PF bleaching gel with the 405 nm LED (group one), Opalescence Xtra Boost PF bleaching gel with 810 nm diode laser (group two), and Heydent bleaching gel with 810 nm diode laser (group three). Bleaching gels with a thickness of 1 mm were applied on teeth surfaces and activated according to the manufacturer's instructions. The temperature change was recorded every second, and the results of the graph showing the peak temperature were plotted using SPSS software. One-way ANOVA was employed to determine the effect of bleaching type on temperature rise. In case of the presence of a significant difference, post-hoc Tukey's test was utilized for pairwise comparison of the groups.

Results: The temperature rise considerably depends on the light sources. Group one (LED + bleaching gel Xtra boost) had the lowest temperature rise (1.87°C ± 0.15), while group two (diode laser + bleaching gel Xtra boost) had the highest temperature rise (3.55°C ± 0.50). There was a statistically noticeable difference in temperature rise among all groups ($P < 0.05$).

Conclusion: The light activation of in-office bleaching gels with the diode laser caused higher temperature changes as compared to LED. However, the detected temperature rise was not critical for pulpal health.

Keywords: Dental pulp cavity, Lasers, Temperature, Tooth bleaching

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Background

Nowadays, many people are seeking esthetic treatments to improve the appearance of their teeth (1). Among these treatments, the conservative and economic nature of bleaching treatment has increased interest in patients and dentists in recent years (2). In the bleaching treatments, different concentrations of hydrogen peroxide, carbamide peroxide, and sodium perborate have been used in the office or at home for vital and non-vital teeth. Most bleaching agents produce hydrogen peroxide that breaks down into free radicals (3). The extent of hydrogen peroxide degradation depends on its concentration and the temperature of the bleaching gel (4). The free oxygen radicals can react with colored organic materials found within tooth structures, leading to a reduction in tooth discoloration (5).

Significant advancements have been made in in-office bleaching treatments by the introduction of some types of coherent and incoherent light sources (6). The halogen lights, LEDs, and diode lasers are the most popular devices utilized for in-office bleaching (7). According to their output range, these light sources accelerate or increase bleaching efficacy by photothermal, photochemical, or photodynamic effects (8).

LEDs and diode lasers, in comparison to other light sources, are cheap, small, and effective and have no noisy parts that should be moved, such as the cooling system (6,7). The difference between these two systems is that

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the diode laser creates coherent light, while LED systems create incoherent light and have low power output (6,7). Laser systems have the ability to thoroughly activate bleaching gels and release more free radicals in a shorter duration (8). The bleaching gels absorb the energy of the light sources that converts to heat; therefore, the temperature of the bleaching gel rises, thereby accelerating the bleaching reaction. The rate of the chemical reaction is doubled by every 10 ˚C rise in temperature (8).

There is a risk that bleaching activating light sources might increase temperature and have side effects on the dental pulp. The effects on pulpal tissue will range from mild teeth sensitivity to pulpal necrosis (9). An increase of about 5.5 ˚C in pulp temperature leads to 15% pulpal necrosis (10). Some studies have shown that different amounts of temperature have been detected depending on the type of light sources used to activate the bleaching process (7,11,12).

Most studies have evaluated the effect of different light sources on pulp temperature with one bleaching gel, and fewer studies have examined this effect using different bleaching gels, especially gels that have been recently released to the market (13). Furthermore, it is important to know an effective and simultaneously safe method in the teeth bleaching process, which has received less attention (14). Therefore, this in vitro study seeks to evaluate the pulpal temperature increase during the in-office bleaching process with different light sources. The null hypothesis is that there is no significant difference in the effects of different light-activated bleaching gels on pulp chamber temperature.

Materials and Methods

According to similar previous studies, the standard deviation of the measured temperature for the three studied groups is 0.66, and it is assumed equal for all groups (11,15). Considering a confidence level of 95%, a statistical power of 80%, and a maximum average difference of 0.9 ˚C, 12 bovine incisor teeth were included in each group (N = 36). Their dimensions were standardized by measuring their mesiodistal and buccolingual dimensions (with ± 2 mm variation). The tooth surface was cleaned from hard and soft tissues by a scaler, and they were inserted into chloramine T for one week at 4 ˚C. Then, the teeth were inserted into normal saline at 24 ˚C.

The roots of the teeth were cut 2 mm below the cemento-enamel junction, and the root canals were widened until the wire of the thermocouple could be inserted inside the pulp chamber. The pulp tissue inside the pulp chamber was removed by a No. 4 round carbide bur (Jota, Switzerland). A long base was prepared to keep the laser beam at a steady distance from the teeth. The wire of the thermocouple (Termopar Digital Multimeter, Tektronix DMM 916, USA) was entered into the pulp chamber from the cemento-enamel junction in a manner that the wire was in contact with the buccal surface of the pulp chamber.

The tips of the Giga diode laser and the LED were fixed in 2 mm (Giga model: DENZA, China) and 6 mm distances from the labial surface of the sample, respectively. The surface of the teeth for bleaching was marked with a circle with a diameter of 3 mm (16,17).

The thermocouple was connected to the monitor of a computer. First, it was necessary to match the numbers on the thermocouple with the program on the monitor. When the temperature of the thermocouple reached the temperature of the room, the bleaching gel was applied on the buccal surface and the radiation started, and the thermal graph for each tooth was saved during the bleaching process.

The samples were divided into three groups. For group one, the Opalescence Xtra Boost PF bleaching gel with a thickness of 1 mm (Table 1) was applied on the surface of the teeth. In addition, an LED (Optilux 501, USA) with an intensity of 1000 mW/cm^2 and a wavelength of 405 nm from a distance of 6 mm was irradiated 6 times, each time for 30 seconds, with a 30-second interval between each irradiation. The total time of bleaching was 330 seconds (Table 2) (16).

In group two, the Opalescence Xtra Boost PF bleaching gel with a thickness of 1 mm was applied on teeth surfaces, and diode laser (Giga model: DENZA, China), with 400 μ fiber, 810 nm continuous wavelength, and 1.5 W power, was irradiated with a 2 mm distance from the buccal surface for 30 seconds. The process was repeated three times, with a one-minute interval between each irradiation. After the last irradiation, the bleaching gel remained on the tooth surface for 5 minutes according to the manufacturer's instructions. The total time of bleaching was 510 seconds. Laser energy in each irradiation and the total irradiated energy were 45 J and 135 J (Table 2), respectively (16,17).

In group three, Heydent bleaching gel (J White Heydent GmbH, Germany) with a thickness of 1 mm (Table 1) was applied on teeth surfaces, and the laser was irradiated in group two (Table 2) (16, 17).

All procedures were performed in the Dental School of Tehran University of Medical Sciences. The mean of the difference between the baseline and the highest temperature was calculated for each specimen and each group. The data were analyzed by SPSS software (IBM SPSS Statistics v21, IBM Corp Chicago, IL). A one-way analysis of variance (ANOVA) test was applied to determine the effect of bleaching type on temperature rise. In case of the presence of a significant difference, post-hoc Tukey's test was utilized for pairwise comparison of groups. The level of significance was considered $P = 0.05$.

Results

A total of 36 bovine incisor teeth were studied in the three mentioned groups. The mean, standard deviation, standard error, minimum, and maximum of the temperature rise in the pulp chamber of the three groups are provided in Table 3. The maximum temperature and

Table 1. Characteristics of Bleaching Gel Used in This Study

Bleaching Agent	Composition	Manufacture	pH	Color
Opalescence Xtra Boost PF	38% hydrogen peroxide, 3% potassium nitrate, and 1.1% fluoride ions (1000 ppm)	Ultradent Products, Salt Lake City, UT, USA	~7	Pink
Heydent (laser activated gel)	35% hydrogen peroxide containing TiO_2 particles that are specific absorbents for diode laser	J White Heydent GmbH, Germany	~7	White

Note. TiO_2: Titanium dioxide.

Table 2. The Methods Used With Bleaching Gels in Four Different Groups

Group	Bleaching Gel	Light Source	Power/Pulse Mode	Number and Radiation Time	Wavelength	Interval Rest Time	Total Time
1	Opalescence Xtra Boost	LED (Optilux 501, USA)	1000 mW/cm² continuous	6 times 30 seconds each time	405 nm	30 seconds each time	330 seconds
2	Opalescence Xtra Boost	Giga diode laser (Giga model: DENZA, China)	1.5 W continuous	3 times 30 seconds each time. +5 minutes gel remaining at the end	810 nm	1 minute each time	510 seconds
3	Heydent	Giga diode laser (Giga model: DENZA, China)	1.5 W continuous	3 times 30 seconds each time. +5 minutes gel remaining at the end.	810 nm	1 minute each time	510 seconds

Table 3. The Mean, Minimum, and Maximum of Pulp Chamber Temperature Rise in Three Different Groups (Light Curing Units + Office Bleaching Gels)

Light Curing Unit + Bleaching Gel	N	Temperature Differences (°C) Mean ± (SD)	Minimum Temperature Differences (°C)	Maximum Temperature Differences (°C)	One-way ANOVA Significant Difference Test
Group 1: LED + Xtra boost bleaching gel	12	1.87 ± 0.15	1.60	2.20	A $P<0.001$
Group 2: laser diode + Xtra boost bleaching gel	12	3.55 ± 0.50	2.40	4.20	B $P<0.001$
Group 3: laser diode + Heydent bleaching gel	12	2.82 ± 0.34	2.40	3.60	C $P<0.001$

Note. SD: Standard deviation; ANOVA: Analysis of variance. The level of significance was considered $P=0.05$. Different letters indicate statistically significant differences.

temperature difference (with the baseline) ranges of the samples in the three groups are shown in Figures 1 and 2, respectively.

Figure 1 displays that the lowest maximum temperature (26.38 °C) was in group 1, indicating that using an LED light with Xtra Boost gel results in the least heat generation in the pulp chamber. The tight confidence interval (CI) suggests (26.18°C ± 0.31) that this combination consistently produces lower temperatures, making it potentially the safest option for avoiding pulp damage. The highest maximum temperature (27.77 °C) with the widest CI (27.41 °C ± 0.55) was observed in group 2. This represents that using a laser diode with Xtra Boost gel generates more heat than the LED, with more variability across the samples. The laser diode combined with Heydent gel (group 3) generates more heat than the LED setup but less than the laser with Xtra Boost (26.94 °C ± 0.41). The CI is narrower than group 2, suggesting that this combination produces more consistent results compared to group 2 but is still higher than group 1.

Figure 2 depicts the temperature difference from the baseline (the increase in temperature due to the bleaching procedure) for the three groups, comparing different light sources and bleaching gels. Group 1 (LED + Xtra Boost bleaching gel) shows the smallest temperature difference (1.87 °C ± 0.15). The tight CI indicates consistent and minimal temperature increases when using an LED light with Xtra Boost gel. This implies that this combination is the safest in terms of thermal impact, as it causes the least change in pulp chamber temperature compared to the baseline. However, group 2 (the laser diode with Xtra Boost gel) exhibits the largest temperature difference (3.55°C ± 0.50), with a broader CI. The higher temperature rise reflects the greater energy output of the laser diode compared to the LED, leading to a more substantial heat increase within the pulp chamber. Group 3 (the laser diode + Heydent bleaching gel) shows a temperature difference (2.75 °C ± 0.77) falling between groups 1 and 2. The laser diode with Heydent gel produces a moderate temperature increase, which is higher than LED + Xtra Boost but slightly lower than laser + Xtra Boost. The narrower CI, compared to Group 2, demonstrates more consistency in this setup.

The results of the one-way ANOVA test revealed that the temperature rise (°C) considerably depends on light sources ($P<0.001$, Table 3). Group 1 (LED + bleaching gel Xtra boost) had the lowest temperature rise (1.87°C ± 0.15), whereas group 2 (the diode laser + bleaching gel Xtra boost) had the highest temperature rise (3.55 °C ± 0.50). There was a statistically significant difference in temperature rise among all groups ($P<0.001$).

Discussion

This experimental study evaluated temperature rise in the pulp chamber with two different light sources and two bleaching gels. The light sources were LED and the Giga

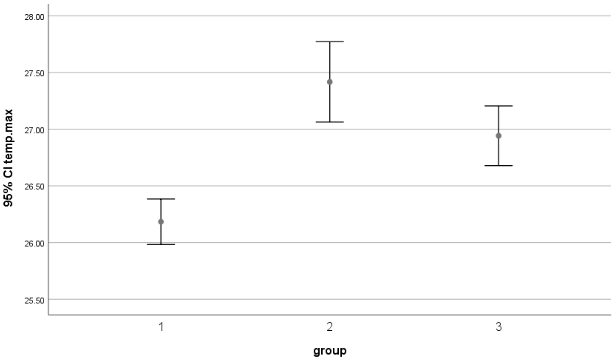

Figure 1. The Maximum Temperature Ranges of Samples in Three Groups: **(1)** LED+Xtra Boost Bleaching Gel, **(2)** Laser Diode+Xtra Boost Bleaching Gel, and **(3)** Laser Diode+Heydent Bleaching Gel

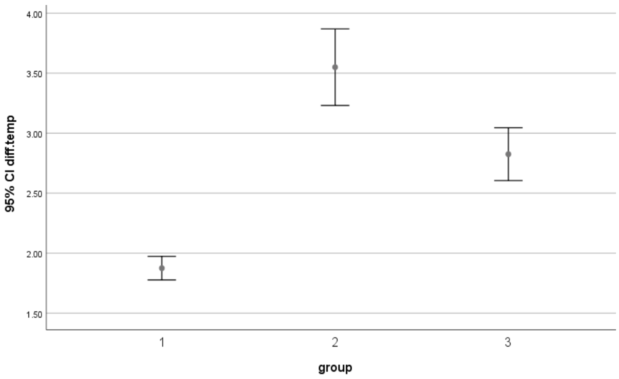

Figure 2. The Temperature Difference (With the Baseline) Ranges of Samples in Three Groups: **(1)** LED+Xtra Boost Bleaching Gel, **(2)** Laser Diode+Xtra Boost Bleaching Gel, and **(3)** Laser Diode+Heydent Bleaching Gel

diode laser, and their mechanism of action was simple and based on the conversion of radiation energy absorbed by the bleaching gel to thermal energy (9).

An increase in pulp temperature resulting from in-office bleaching procedures is clearly undesirable and harmful, as it can lead to irreversible damage to pulpal tissues. As outlined by Zach and Cohen, researchers have commonly used a 5.6°C rise as the threshold for thermal damage (15-17). It has been claimed that this study is old, and its methodology has faced significant scrutiny (10,12). Many researchers have reported the lack of loss of pulp vitality at the proposed temperature threshold and suggested higher critical points for pulpal health (8-11). Additionally, more recent research has shown that an intrapulpal temperature increase of around 11.2 °C did not result in necrotic or reparative changes in tooth tissues (10-13). Despite these findings, the precise threshold for irreversible pulp damage remains debated (10,13). Variations in long-term outcomes across studies may be due to different heat application methods and experimental approaches. However, temperature rise ranges in the present research were lower than the mentioned critical pulpal temperature rise in different previous studies in all groups (10-17).

LED light sources have become widely adopted in dental bleaching due to their efficacy and relative safety (18). They emit specific wavelengths of light that can effectively activate bleaching agents while generally producing minimal heat (19). Studies have shown that LED systems typically result in a lower increase in pulp temperature compared to older technologies such as halogen or xenon arc lights (18-20). The lower heat generation is primarily due to the nature of LEDs, which are designed to emit light with reduced thermal output (20). This characteristic not only enhances patient comfort but also reduces the risk of adverse effects on the pulp (18-20). These findings are consistent with those of the current study, demonstrating that LED+bleaching gel Xtra boost had the lowest temperature rise. However, while LED systems generally maintain a more stable pulp temperature, practitioners should still be cautious. The risk of temperature rise can vary depending on the intensity and duration of light exposure, as well as the specific LED system used (9,19). Ensuring that the LED system is properly calibrated and adhering to recommended treatment protocols are essential to mitigate any potential risks (9,13).

Diode lasers represent a more advanced option for light activation in bleaching procedures (21). They provide highly focused, monochromatic light that can accelerate the bleaching process (22). The precision of diode lasers allows for efficient activation of bleaching agents, but their impact on pulp temperature needs careful consideration (23). In this study, an 890-diode laser was used, which resulted in a significantly higher temperature increase, but this increase was within the safe range for the pulp. This finding is in line with the results of previous studies that utilized similar wavelengths (21-27). However, the reported range for temperature increase is somehow different in various studies (21-27). Some other studies indicated that diode lasers can lead to a notable increase in pulp temperature when high-intensity settings are employed or when the laser is applied for extended periods (8-10). The concentrated light generated by diode lasers, while effective for bleaching, can lead to localized heating (8-10). To reduce this risk, it is crucial to use diode lasers with appropriate power settings and limit the exposure time. Additionally, incorporating cooling techniques, such as using a water spray or air-cooling system, can help manage and reduce pulp temperature rise (7-9).

When comparing LED and diode laser systems in terms of pulp temperature rise, LED systems generally offer a safer profile due to their lower thermal output (28). In contrast, diode lasers, while being highly effective in activating bleaching agents, require more meticulous management to prevent excessive temperature increases (29). It should be noted that most of these results were based on in vitro studies. One specific clinical study utilized a hybrid light source (LED/laser) on the enamel surface during 35% hydrogen peroxide bleaching. A hybrid light source could influence temperature variations on the enamel surface but was not related to greater tooth sensitivity (30). It can be due to the dentinal fluid in vital teeth that provides more thermal insulation to the pulp (30).

Therefore, the choice between these technologies should balance treatment efficacy with considerations for patient safety and comfort. Ensuring proper calibration and adherence to safety protocols is vital for minimizing the potential for adverse effects (8,30).

Another important factor that must be considered in relation to the increase in pulpal temperature is the use of protocols with and without the application of the bleaching gel. It has been shown that significant increases in pulp temperature can happen even without gel application. The bleaching gel applied to the buccal surface of the teeth can act as an insulator, reducing the temperature rise in the pulp chamber in comparison with no gel application (9,13). However, in another study, the application of the gel had the opposite effect (19). Contradiction in the results of different studies can be related to differences in the activation time, approach, and materials.

Hydrogen peroxide concentration is a crucial factor in dental bleaching, influencing both the effectiveness and safety of the treatment (1). High concentrations are effective for rapid and significant whitening but come with potential risks such as increased sensitivity. Lower concentrations provide a safer, more gradual approach but require more time to achieve comparable results (3). In-office treatments often use concentrations ranging from 15% to 40% HP, allowing for significant color changes in a single session. These higher concentrations are effective because they increase the speed of the chemical reaction that breaks down stain molecules (4). Some studies evaluated the effects of low and high hydrogen peroxide concentrations of in-office dental bleaching associated with different light activation systems (31-33). Greater penetration of hydrogen peroxide was observed within the pulp chamber, as well as color change when using 35% (high concentration) hydrogen peroxide in some studies (31-33). In addition, in-office bleaching gels are usually marketed at different pH rates that can have effects on diffusion in the pulp chamber and color change (34,35). In the present study, almost the same and common percentage (35% and 38%) of hydrogen peroxide and the same pH rates were used in tested in-office bleaching gels in order to reduce the confounding effects.

The bleaching gels in this study contained coloring agents. The interaction between coloring agents and light systems can influence the effectiveness and safety of the bleaching process (36). Coloring agents can affect how light penetrates the gel and interacts with the bleaching agents (36). While many colorants are designed to be transparent or minimally obstructive to light, intense or opaque colorants might interfere with the light's ability to activate the bleaching agents effectively (1). Some light activation systems generate heat, which can be affected by the presence of coloring agents (24). It should also be noted that the Heydent bleaching gel utilized in the present study contained titanium dioxide (TiO_2) particles. TiO_2, a photocatalytic material used in tooth bleaching, can form free radicals when activated by light (37). TiO_2 has also been shown to react at visible light exposure of 400 nm, which is the same wavelength of common light curing unit sources employed in dentistry (38). Previous studies have shown that the addition of visible-light-activated TiO_2 to HP-based bleaching agents can improve bleaching efficiency due to more light that can be absorbed into the bleaching gel instead of the tooth surface (37-40).

In the present research, the diode laser produced the highest temperature rise when used with Xtra Boost gel, which has a pink color. These results might be due to the differences in the pigments, colored materials, and other compositions (e.g., TiO_2) in different bleaching gels that can affect diode laser absorption.

According to the results obtained regarding measuring the increase in pulp temperature and comparing the data with the findings of previous studies, the following can be stated as the causes of discrepancy or agreement:

Environmental temperature, the level of expertise of the person conducting the test, the concentration of applied gel, the thickness of the gel on the buccal surface, the color of the bleaching gel, the thickness of the dentin and enamel, the radiation method, the duration of bleaching, the laser wavelength, the distance between the laser tip and tooth surface, and many other factors affect the results.

Therefore, within the scope of the experimental conditions of the present study, more care should be taken when using the laser device with the Xtra boost gel. Further, even though Heydent gel is designed to activate with laser, it is suggested that future studies investigate the difference between Heydent gel with LED and laser radiation. It should be noted that in oral conditions, these results may vary, and clinical studies should obtain more reliable results.

Conclusion

Under the simulated conditions and within the limitations of this in vitro study, there was a significant difference among different light-activated bleaching gels tested on pulp chamber temperature rise. Light activation of in-office bleaching gels with a diode laser caused higher temperature changes as compared to LED. However, the detected temperature rise was not critical for pulpal health.

Authors' Contribution

Conceptualization: Elmira Ataee, Ladan Ranjbar Omrani, Elham Ahmadi.
Data curation: Mandana Karimi, Elmira Ataee.
Formal analysis: Mandana Karimi, Elmira Ataee.
Investigation: Mandana Karimi and Elmira Ataee.
Methodology: Elmira Ataee, Ladan Ranjbar Omrani, Mahdi Abbasi, and Elham Ahmadi.
Project administration: Elmira Ataee, Ladan Ranjbar Omrani, Mahdi Abbasi, Elham Ahmadi.
Resources: Mandana Karimi, Elmira Ataee.
Software: Mandana Karimi.
Supervision: Ladan Ranjbar Omrani, Mahdi Abbasi, Elham Ahmadi.
Validation: Ladan Ranjbar Omrani, Mahdi Abbasi, Elham Ahmadi.
Visualization: Ladan Ranjbar Omrani, Mahdi Abbasi, Elham Ahmadi.
Writing–original draft: Mandana Karimi.

Writing–review & editing: Mandana Karimi, Elham Ahmadi.

Competing Interests

The authors declare that there is no conflict of interests.

Ethical Approval

This study was approved by Tehran University of Medical Science as a thesis with project number 8711272039.

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