Photodiagnosis and Photodynamic Therapy 31 (2020) 101900

Contents lists available at ScienceDirect

Photodiagnosis and Photodynamic Therapy

journal homepage: www.elsevier.com/locate/pdpdt

In vitro evaluation of the effectiveness of bleaching agents activated by KTP and Nd:YAG laser

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ARTICLE INFO

Keywords:
Tooth bleaching
Hydrogen peroxide
Photodynamic bleaching

ABSTRACT

Aim: To compare two different laser sources, a KTP laser with a wavelength of 532 nm and a Nd:YAG laser with a wavelength of 1064 nm, to investigate the relation between laser source and bleaching gel during laser irradiation.

Methods: Extracted human teeth were stained and randomly divided into six groups. Two in-office bleaching gels, Beyond and Opalescence Boost, were applied to stained teeth and then irradiated at either 532 nm or 1064 nm. The temperature change of pulp chamber was measured. The color change (ΔE*) was evaluated at the following time points: immediately after bleaching, 7, 14 and 30 days after the end of bleaching.

Results: Boost irradiated by KTP laser showed the higher temperature increase when compared with Beyond irradiated KTP and Nd:YAG. Boost irradiated by Nd:YAG presented lower temperature increase than by KTP. All groups showed a certain color change. After bleaching, Nd:YAG laser irradiation did not increase the ΔE* value significantly compared with gels without laser ($p > 0.05$). At each time point, Boost activated by KTP laser showed higher ΔE* value compared with other groups ($p < 0.05$), but decreased significantly 15 days after the end of bleaching. The other groups showed a relatively small change in ΔE* value after 30 days ($p > 0.05$).

Conclusions: KTP laser achieved better results than the Nd:YAG laser regarding tooth color change when associated with the Opalescence Boost bleaching gels.

1. Introduction

Tooth discoloration is becoming an increasingly common aesthetic problem. Bleaching of teeth has become an important component of aesthetic dentistry, representing the most conservative treatment of discolored teeth. In-office bleaching usually utilizes highly concentrated hydrogen peroxide (HP) as active agent. Bleaching mechanism is based on the ability of active agent to penetrate the tooth structure and produce free radicals that oxidize the colored organic molecules [1]. Of the stains which occur in tooth structure, one of the most difficult groups to bleach is that caused by tetracycline antibiotics, which readily bind to the dentin of teeth after systemic administration of these antibiotics during tooth formation [2]. For achieving good results and also in a shorter time, there is a growing interest in the use of intense visible light sources for enhancing the action of hydrogen peroxide-based bleaching gels.

Laser tooth bleaching officially started in 1996 with the FDA approval of the argon (488/514 nm) and carbon dioxide (10,600 nm) lasers to activate tooth bleaching solutions, in 2007 the diode laser (980 nm) received FDA approval. Recently, photodynamic bleaching in the dental office has been viewed as an ideal treatment, being minimally invasive and relatively time efficient. a novel technology for tooth bleaching (Smartbleach®) was developed to exploit photodynamic reactions for the purpose of bleaching teeth [3]. In this system, a KTP (potassium-titanyl-phosphate) laser, which emits visible green light at a wavelength of 532 nm, is used to activate the potent photosensitizer rhodamine B dye under high-pH (pH = 9.5) conditions in an aqueous gel [4]. It is thought that the perhydroxyl radical is produced from HP under these alkaline conditions [5]. However, it is also reported that Smartbleach® was in the slightly alkaline pH range (7.2 ± 0.1) [6]. Moreover, KTP laser bleaching differs from other light-activated bleaching systems, its interest consisting in the possibility to break the tetracycline molecules, to eliminate greyish colorations when used associated to a red-colored gel [7]. It is reported that

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https://doi.org/10.1016/j.pdpdt.2020.101900
Received 27 February 2020; Received in revised form 21 June 2020; Accepted 22 June 2020
Available online 24 June 2020
1572-1000/ © 2020 Published by Elsevier B.V.

photodynamic bleaching employed the KTP laser is without significant adverse effects on the oral soft tissues, dental pulp or tooth structure [6,8]. Walsh LJ reported that the energy transfer of KTP laser results in controlled heating of the gel and not the tooth, minimizing the damage to the dentine pulp complex [9]. Furthermore, because of its specific wavelength, it may photooxidize the chelates formed between tetracyclines and hydroxyapatite or calcium orthophosphate [10].

In this study, a KTP laser and a Nd:YAG laser were used to activate two in-office bleaching gels with different HP concentrations, pH and gel color. The aim of this study was to compare the results of thermal elevation and bleaching efficacy alone and with laser irradiation, to investigate the relation among laser source, bleaching gel and color change.

2. Material and methods

In this study, the crowns of human teeth were submitted to different HP bleaching agents. Two bleaching gels were evaluated: a 35 % HP (pH = 4.03, Beyond, Beyond Tech Corp, USA); a 38 % HP (pH = 7.52, Opalescence Boost, Ultradent, USA). Laser irradiation was performed using an all-solid-state single frequency Nd:YVO_4/KTP laser device (State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Optoelectronics, Shanxi University) [11].

2.1. Tooth stain

The protocol for this study was reviewed and approved by the Ethics Committee of the Shanxi Bethune Hospital. Thirty human maxillary permanent central incisors and Thirty premolars extracted were selected as samples. Crowns with caries, restorations, or fractures were discarded. All teeth were then stored in 4 ℃ distilled water containing 0.2 % thymol to inhibit microbial growth until use. Orange II ($C_{16}H_{11}N_2NaO_4S$) were diluted with distilled water to a concentration of 0.15 mM solution. All teeth were immersed for 72 h in an Orange II solution using the method described by Lee and others [12].

The samples of incisors and premolars were divided into six groups (n = 5) respectively: Group BE, Beyond only; Group OB, Opalescence Boost only; Group K−BE, Beyond with KTP laser irradiation; Group K−OB, Opalescence Boost with KTP laser irradiation; Group N−BE, Beyond with Nd:YAG laser irradiation; Group N−OB, Opalescence Boost with Nd:YAG laser irradiation.

2.2. Temperature measurement

The remnant pulp tissue of incisors was removed of these teeth using endodontic type K-files introduced by apical access and root canals were enlarged with # 80 K-file in order to allow the placement of the thermocouples in the pulp chamber. The root canals were filled with a thermally-conductive paste (7783D, ShinEtsu, Japan). A K-type thermocouple probe (MF5E-103 F, Sen'en, China) with a digital thermometer (DM3058, Rigol, China) was used to measure the temperature increase in the pulp chamber. The probe was inserted into the pulp chamber and the end is in contact with the buccal wall.

After the thermocouple was introduced, the root stub was then secured to an acrylic plastic base with an autopolymerizing resin. We placed each peroxide bleaching gel in an approximately 2 mm thickness on the outer enamel surface. The irradiation conditions were a spot size of 5 mm, output powers of 800 mW and irradiation times of 180 s. The power density was 4.2 W/cm^2. Thermal recordings started 5 s before laser irradiation and ended in time with laser irradiation. The recorded ambient room temperature was 25.0 ± 0.8 ℃ during experiment.

2.3. Color measurement

The samples of premolars were measured for tooth color before and after the bleaching procedure. The gels were irradiated for 20 s using laser with the same parameters, then were left on the tooth surface for 15 min. The energy density was 84 J/cm^2. A circular area was measured at the middle third region of crown. The color distributions were measured by the CIE-lab system using a dental colorimeter (Crystaleye, Olympus, Japan). In this system, the "L*" represents the degree of gray and corresponds to a value of brightness. The "a*" is a parameter in the red-green spectrum and "b*" is a parameter in the blue-yellow spectrum. In the meantime, the samples were stored in artificial saliva in light-protected containers. The solutions of artificial saliva were changed every 2 days. The samples were inspected before the bleaching, 1, 7, 14 and 30 days after the bleaching to measure the color changes nL*, na*, nb*, which indicated the increased values of L*, a* and b*. The overall color difference ΔE* from the three measurements was calculated as follow [13]:

$$\Delta L^* = nL^* - 0\,L^*, \quad \Delta a^* = na^* - 0a^*, \quad \Delta b^* = nb^* - 0b^*, \quad \Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

The data was statistically analyzed by one-way analysis of variance (ANOVA) test and *t*-test. Statistical significance was set at $p < 0.05$.

3. Results

Temperature rise values are showed in Fig.1. The temperature Change in K−OB groups (15.43 ± 2.93 ℃) was significantly higher than those of other groups ($p < 0.05$). The BE and OB groups produced the lowest temperature increase ($p > 0.05$). The K−BE, N−BE and N−OB group had similar temperature increase ($p < 0.05$), with the value of 8.87 ± 2.10 ℃, 7.89 ± 2.23 ℃ and 8.18 ± 1.96 ℃, respectively. When irradiation time was within 20 s, the temperature variation of all groups did not exceed 5.5 ℃, the threshold for potential harm to pulp tissue (Table 1).

The graphic representation of ΔE* for each interval is shown in Fig. 2. All groups showed a certain color change. After bleaching, Nd:YAG laser irradiation did not increase the ΔE* value significantly compared with BE and OB group ($p < 0.05$). K−OB group showed the largest ΔE* value among all groups ($p < 0.05$), but decreased significantly 15 days after the end of bleaching. The other groups showed a relatively small change in ΔE* value after 30 days ($p > 0.05$).

4. Discussion

Tea, blood and chlorhexidine are used to simulate the discoloration of teeth, but there are some shortcomings, such as the long-time process of staining, the difficulty to determine the stain components and limited repeatability of staining substances. The dye should meet the following requirement [12]: (1) The chemical formula of the selected dye could simulate the stain of the tooth. Namely, the dye should exhibit similar structures to pigmented carbon-ring compounds or carbon double-bond compounds [14]; (2) The molecular weight of the selected dye was small enough to easily penetrate into the tooth structure; (3) The selected dye could be decomposed by HP. In this paper, Orange II solution was selected to stain the teeth and evaluate the bleaching ability in vitro. Orange II solution was thought to be able to stain the teeth quickly with high repeatability, and can be effectively bleached by hydrogen peroxide. The reaction formula of Orange II with HP was supposed to be the following [15]:

$$C_{16}H_{11}N_2NaO_4S + (37/2)O_2 + (9/2)H_2O_2 \rightarrow 16CO_2 + 8H_2O + 2NO_3^- + NaHSO_4^- + 3H^+$$

Moreover, the degradation of Orange II could be accelerated by light activation. The reason might be that the formation of ˙OH under light irradiation increased [16]. The bleaching ability of HP is based on the generation of free radicals (HO2 ˙, HO˙) derived from HP. Various light sources with different wavelengths were employed for the purpose of energizing the HP, such as halogen light (400 − 500 nm), Infrared

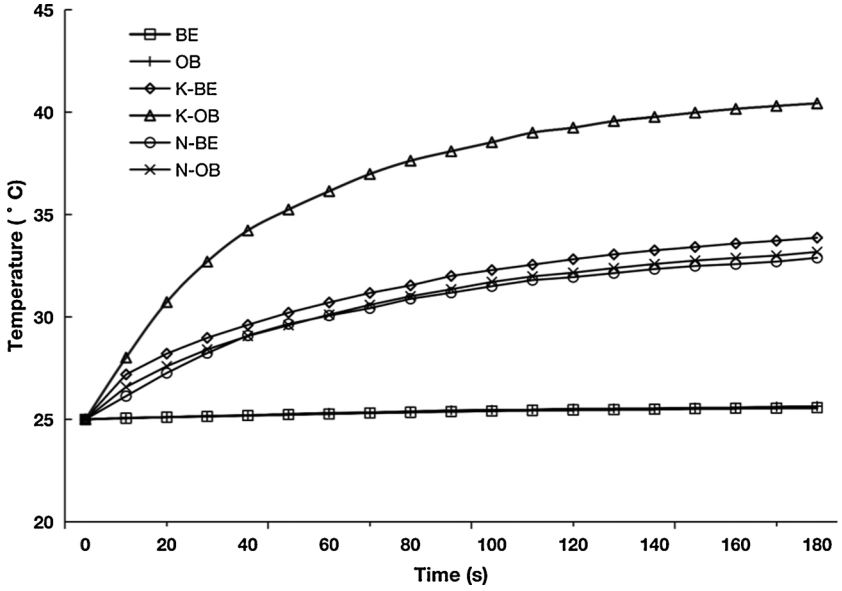

Fig. 1. Temperature increase for the dental pulp according to time.

Table 1
Intrapulpal temperature rise values (°C) with lasers and bleaching agents after 20 s irradiation (X ± S). Groups identified with the same letter do not differ statistically ($p < 0.05$).

Light	Bleaching agent	
	Beyond	Opalescence Boost
No light	0.12 ± 0.02[a]	0.14 ± 0.02[a]
Nd:YAG laser	2.40 ± 0.62[b]	2.60 ± 0.44[b]
KTP laser	3.71 ± 0.58[b]	5.13 ± 0.54[c]

Groups identified with the same letter do not differ statistically.

light (2000 − 4000 nm), light-emitting diodes light (535 nm) and lasers. It is believed that light source ability to heat HP can increase the rate of decomposition of oxygen to form oxygen free radicals and enhance the release of stain-containing molecules [17].

In order to ensure the safety of laser irradiation, it is necessary to evaluate the temperature change of pulp chamber. In this paper, KTP and Nd:YAG laser sources were used. When Nd:YAG laser beam (1064 nm) goes through the solid medium of KTP crystal, its wavelength decreases into 532 nm. KTP laser has very similar characteristics to Nd:YAG. It has relatively low absorption in water and tooth mineral, high absorption in hemoglobin and medium penetration depth into dental hard tissue [18]. In this study, the results showed that the temperature of pulp chamber in each experimental group irradiated by laser increased significantly. The temperature change in K−OB group (15.43 ± 2.93 ℃) was significantly higher than that in other groups. It may be caused by the different color of two gels. Beyond bleaching agent is in white color, and Boost bleach is in orange to dark red color. In general, laser has the maximum absorbance to the material in complementary color. Red and green, yellow and blue is the pair of complementary color respectively. In the Smartbleach® system, KTP laser is used to activate the photosensitizer rhodamine B in a red bleaching gel. In this study, the addition of beta carotene as photosensitized by manufacturer of Opalescence Boost improved the ability

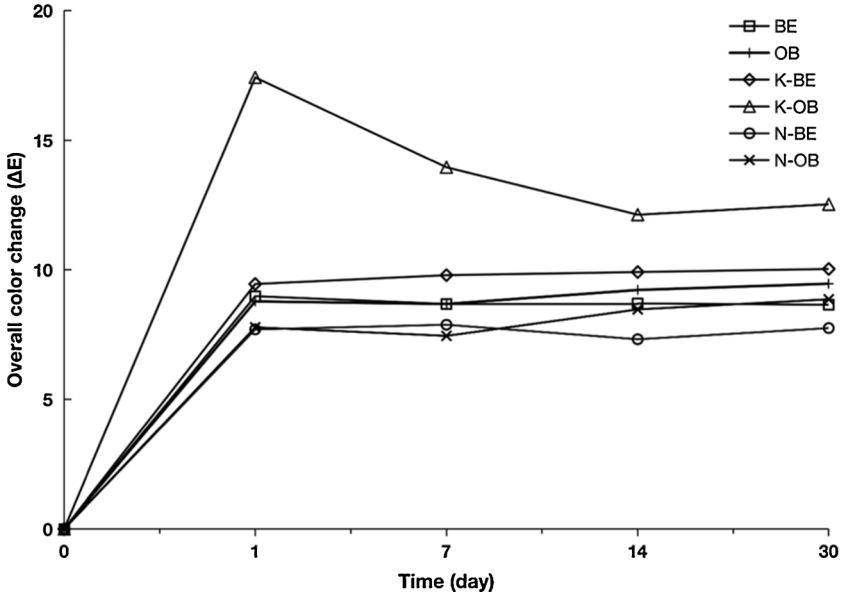

Fig. 2. Change in ΔE* values in 30 days.

to absorb KTP laser. Zach et al. reported that the increase of 5.5 ℃ in tooth temperature will cause pathological changes in pulp tissue, and the increase of more than 16.6 ℃ will cause irreversible changes in all pulp [19]. Considering thermal damage to the pulp, the irradiation time in this study was limited to 20 s.

Bleaching efficacy is another concern when applying bleaching lights. Shade was compared in terms of ΔE* values determined before and after laser irradiation. The difference in the two values is a concrete indicator of the changes in shade. ΔE* > 3.3 were considered perceptible to the naked eye [20]. The ΔE* value greater than 3.3 was obtained in each group at each follow-up examination. The ΔE* between OB and BE group did not present significant differences, due to the similar HP concentration. The different pH value did not affect the color change. The bleaching ability of HP is based on the generation of reactive oxygen species ($HO2^{\cdot}$, $HO^{\cdot}$). These free radicals can attack the colored stains (chromophores) above the enamel surface or inside the tooth structure. The higher the reactivity of oxidants are, the more effective the agent will bleach chromophores [21]. In general, it is considered that HP based bleaching can be enhanced through six methods: alkaline environment, photochemistry, photothermal effect, direct photobleaching, photolysis effect, photocatalysis and photodynamic effect. Compared with Opalescence Boost gel(pH = 7.52), Beyond gel had the similar concentration of HP but a lower pH value (pH = 4.07). It has been reported that HP becomes much more reactive at pH values above 7 [22]. The results of color measurement found that bleaching effect of BE group was similar to that of OB group, suggesting the pH value did not affect the final bleaching efficacy. When bleaching gel was enhanced by laser source, laser-tissue interactions are optical effects, or photochemical effects, or both of them at low irradiation. When laser power is increased, photothermal interactions begin to dominate. Light will be absorbed by molecules inside the gel or tooth structures, leading to molecular vibration and consequent heating [23]. If light is projected onto a bleaching gel, a small fraction is absorbed and its energy is converted into heat. The conversion of visible light into heat is only possible in the event of absorption of the respective photons. The absorption is the important factor for a temperature rise within the bleaching gel, dental hard tissue or pulpal tissue, which depends on the wavelength and substance. As long as the wavelength of light is appropriate, it can be absorbed by substances. If the chromophores peak of absorption is not matched exactly with the related wavelength, there will be no benefit from adding a laser to the treatment. Therefore, variable results with dental bleaching procedures reported in the literature can be explained by considering that bleaching effects depend on the chromophores, the nature of the enamel, the wavelength, and the pH and colorant of the gel. In this study, both bleaching gels irradiated by Nd:YAG (1064 nm) did not showed a significant increase of ΔE*. The result is consistent with previous research. Marcondes et al. used a Q-switched Nd:YAG laser and recorded a lower increase in temperature in the pulp chamber, although this not associated with a better bleaching performance [24].

The ΔE* of K−OB group was significantly higher compared to the other groups. These results suggested that beta carotene photosensitive excited the absorption of KTP laser. The photodynamic enhancement enabled formation of hydroxyl radicals and singlet oxygen with the very high reactivity, and is thus a very powerful enhancement [22]. Although the pulp temperature change in K−OB group was significantly higher than those in other groups at each time, the better bleaching efficacy might not a result of thermal effect. Fornaini et al. used a diode laser and a KTP laser to irradiate a white 30 % HP gels in different power. The diode laser led to a higher temperature (74.91 ℃), but the change in shade was not significantly better than KTP laser [25].

5. Conclusion

Based on the data obtained in the present study, it can be concluded that the KTP laser achieved better results than the Nd:YAG laser regarding tooth color change when associated with the Opalescence Boost bleaching gels.

Acknowledgment

This study was supported by the Science and Technology Program of Shanxi Province (No. 20130313015-8).

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