



Effect of lights with various wavelengths on bleaching by 30% hydrogen peroxide

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Abstract

The objective of this study was to evaluate the bleaching effect of light sources with various wavelengths using 30% hydrogen peroxide (HP) in vitro. The hematoporphyrin-stained paper was bleached with HP and irradiated for 10 min using LED light sources with 265, 310, 365, 405, or 450 nm respectively. In control group, HP was applied for 10 min without light irradiation. The bleaching procedure was repeated two times. The $L^*a^*b^*$ values of the samples before bleaching and after each bleaching step were measured using a colorimeter. Color changes of specimens were then calculated and statistically analyzed. There was an interaction between light sources and time of irradiation in the color change ($p < 0.05$). Time and light sources significantly affected ΔE and ΔL ($p < 0.05$). The light source of 256 nm showed the highest bleaching effect over time followed by that of 310 nm, which were statistically different from other groups ($p < 0.001$). The 365 nm, 450 nm groups, and control group showed low bleaching effect visually with no significant differences in ΔE and ΔL ($p > 0.05$). It was concluded that the wavelengths of the light sources affected the bleaching by HP. The 310-nm light can be a potential source for bleaching.

Keywords Bleaching · Ultraviolet · Hydrogen peroxide · LED · Wavelength

Introduction

Tooth bleaching has become rapidly popular in cosmetic dental treatment, boosted by the dual need of healthy and esthetic appearance because it is a cost-effective and conservative method. Three kinds of tooth bleaching techniques are walking bleach, in-office bleach, and at-home bleach. The most

utilized products for in-office bleaching contain 30–35% hydrogen peroxide— H_2O_2 (HP). In order to provide a faster and more effective treatment, in-office bleaching agent has been used in association with an energy source. Light source can activate the peroxide in photosensitive bleaching agent to accelerate the chemical redox reaction of the bleaching procedure [1]. The ingredients in the light-activated bleaching agents can facilitate transferring energy from the light to hydrogen peroxide and colored materials such as beta carotene and manganese sulfate [2]. A number of studies have utilized light sources with different wavelengths and spectral power characteristics such as quartz tungsten halogen lights, mercury vapor lamps, plasma arc lamps, lasers, and light-emitting diodes (LED). It was reported that prolonged irradiation time and high temperature resulted from high-intensity light sources could damage the pulpal tissue of vital tooth [3]. Diode laser (15-s irradiation under bleaching mode at 10 W with continuous wave) caused temperature changes that may adversely affect patient's sensitivity and pulpal health, while LED (40-s irradiation with 380 mW/cm² light intensity) produces lower temperature [4]. A combination of bleaching agent and light showing critical color change and less temperature rise should be considered for in-office tooth bleaching for a safe treatment.

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The bleaching effect of HP depends on the extent of hydroxyl radicals generated from the reaction of HP degradation. Ultraviolet (UV) was introduced in bleaching procedure. Ultraviolet (UV) tends to be absorbed by HP, inducing the molecular vibration and degradation of HP [5]. The whitening effect was improved 26% when photo-Fenton activator was used in combination with UV light (Zoom2, Discus Dental, 350–400 nm, 2000 mW/cm²) [6]. However, the Zoom2 light source produced the large increase in mean pulpal and tooth surface temperature of 21.1 and 22.8 °C under 15 min of irradiation [7].

Narrowband UVB with a narrow peak has less side effects on human tissue compared to broadband and showed higher therapeutic effect compared to other UV therapies [8]. However, the bleaching effect of UV light from narrowband of LED was not been investigated. Therefore, the objective of this study was to evaluate the bleaching effect of light sources with various wavelengths using 30% HP in vitro. The null hypothesis was no difference in bleaching effect between the groups using different lights.

Methods and materials

LED light sources

The light sources employed in this study were experimental LED light units (Nikkiso, Tokyo, Japan) with different peak wavelengths ranging from UV (265, 310, and 365 nm) to visible lights (405 and 450 nm). The output power of each LED was determined to obtain the power density of approximately 10 mW/cm² (Table 1). The external diameter of tip was 6 mm. The distance between light source and the irradiated surface of sample was fixed approximately 1 mm.

Preparation of HP paper and bleaching procedure

The bleaching effect of each light source was determined using hematoporphyrin-stained paper, prepared by staining glossy paper for inkjet printer with hematoporphyrin mixed in ethanol. The papers were covered by a vinyl masking tape with a 5-mm diameter hole corresponding to the LED light tip to obtain the experimental surface. Thirty percent hydrogen peroxide (HP, Wako Pure Chemical Industries Ltd., Osaka, Japan) was used as bleaching agent without any additive such as thickener, pH conditioner or catalyst. The pH of hydrogen peroxide used in this study was 3.5. Four microliter HP was applied adequately to the hole surface and the paper was irradiated for 10 min using each LED. In the control group, the papers were applied with HP without any irradiation. After irradiation, HP was removed before image of the hole surface was taken and color was measured. The bleaching procedure and color measurement were repeated for two times.

Color measurement

A colorimeter (RC5000, PaPaLaB, Shizuoka, Japan) was used for color measurement in this study. The images of papers were captured over a black background (EVER BLACK, No. 0005, Evers, Osaka, Japan) using a CIE XYZ camera from a distance of 20 cm, duration time 0.2 s with shutter speed of 1/1000 to 1/15 s. The camera is equipped with spectral transmittance derived from the CIE color matching functions in XYZ color system [9, 10]. Thanks to the embedded color calibration system with a spectrophotometer mounted inside the optical systems, the outputs of the camera are linearly transformed into device-independent XYZ tristimulus values.

The color of the stained paper circle was measured as a baseline. The papers with $L^* = 27.9$ (23.5–32.7), $a^* = 15.3$ (13.2–17.2), and $b^* = 15.78$ (16.5–19.5) respectively were included in this experiment ($N = 10$).

Since the internal LED diameter was less than 5 mm and the intensity was not strong, the color changed by bleaching was not uniform, the region of interest (ROI) was selected with fixed size of 2×2 mm at the center of the circle on the image covering the area denoting the color change. $L^*a^*b^*$ values were obtained by RC500 at baseline and after 10 min and 20 min bleaching in the same location.

The difference of L^* , a^* , and b^* at each period of bleaching was represented under ΔL , Δa , and Δb respectively. The color difference (ΔE) was calculated following equation:

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

The procedure of experiment is illustrated in Fig. 1.

Statistical analysis

The distribution of data in each group was normal (Kolmogorov Smirnov $p > 0.05$), parametric tests were performed. ΔE and ΔL data were subjected to two-way ANOVA, with the light sources and treatment time as factors. The statistical procedures were analyzed at 0.05 significance level using IBM SPSS Statistics 23 Software (Chicago, IL, USA).

Results

Figure 2 presented photographs of typical color change after bleaching procedure of representative specimens in each experimental group. The bleaching effect of 265-nm wavelength light reached its peak after 10 min, followed by that of 310 nm after 20 min, while there was not visible change in other groups. The result delivered by UVC (265 nm) irradiation after 10 min was indicated by the uniform bright circle with

Table 1 Specification of the light sources used in the study

Wavelength (nm)	265 (UVC)	310 (UVB)	365 (UVA1)	405 (Violet)	450 (Blue)	Control
Output power (mW)	350	90	150	110	90	No irradiation
Power density (mW/cm ²)	10.54	10.1	10.8	10.3	10.9	

the diameter of 4 mm at center of hematoporphyrin paper. For UVB (310 nm), at 10 min, there was merely a bright dot at the center of irradiation area, whereas at 20 min, the bleached part became more evident, with the center being consistently brightest.

The visual observation was confirmed by the change of color parameters. The ΔL , Δa , Δb , and ΔE value of each group were presented in Fig. 3. After bleaching, L^* increased while a^* and b^* decreased. Δa and Δb were represented in absolute value because they were both negative. It required 20 min for 310 nm to reach ΔL and ΔE close to that of 265 nm.

Two-way ANOVA showed that the time and light sources significantly affected both ΔE and ΔL^* . There was significant difference between ΔE and ΔL between 265, 310 nm, and the other group ($p < 0.05$).

Discussions

This study was conducted to evaluate the bleaching potential of various wavelengths of UV light in comparison with two different wavelengths of visible lights. The methods for assessment of color shades changes before and after bleaching are visual analysis, spectrophotometer, colorimeter, and image analysis techniques with software [11]. Although the colorimeter is simple to use and frequently applied in tooth bleaching study,

the measured surface needs to be covered by the contact tips. In this study, only LED unit with intensity of 10 mW/cm² was available as an experimental prototype provided by the company. The low intensity and the internal diameter of LED of less than 5 mm might render the area of color change to be ununiform and rather smaller compared to the probe tip of colorimeter. Therefore, colorimeter incorporated with CIE XYZ camera was used to assess the color of hematoporphyrin papers. Three optical filters that are mathematically equivalent to linear combinations of CIE color matching functions depict pixels values by CIE XYZ tristimulus values per pixel. The color calibration system with spectrophotometer allows the exact and repetitive evaluations of colors. Spectral information obtained from the object were followed by accurate colors acquisition of the ROI [9].

In a quest to understand the bleaching effect of lights with wavelength, hematoporphyrin-stained paper was used. The trauma-related discolored tooth was caused by the stains result from blood break down products [12]. Hematoporphyrin is a blood pigment and hematoporphyrin and its derivatives can be chromogen of discolored tooth. Hematoporphyrin is thought to be appropriate for examination of bleaching. Hematoporphyrin papers were already used for the study on bleaching [13, 14].

The light of 265 nm produced fastest bleaching effect followed by 310 nm. However, due to the sensitivity of paper

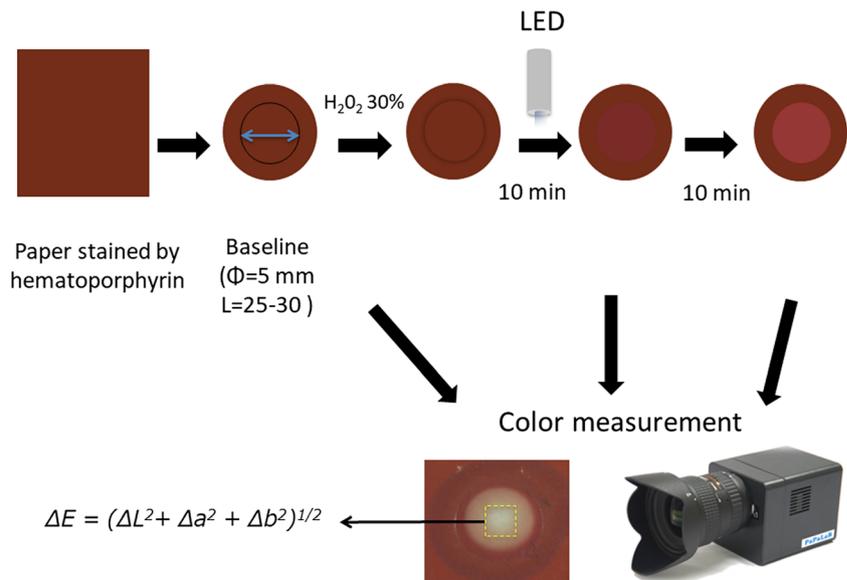
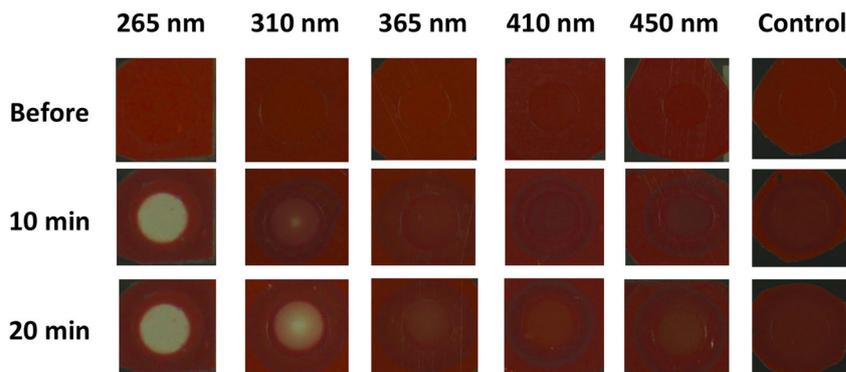
Fig. 1 Methodology of the study

Fig. 2 Representative images of bleaching results



to the light, difference was not observed in 365 and 405, 450, and control. The light energy (photon energy) is expressed following equation;

$$E = hc/\lambda \tag{2}$$

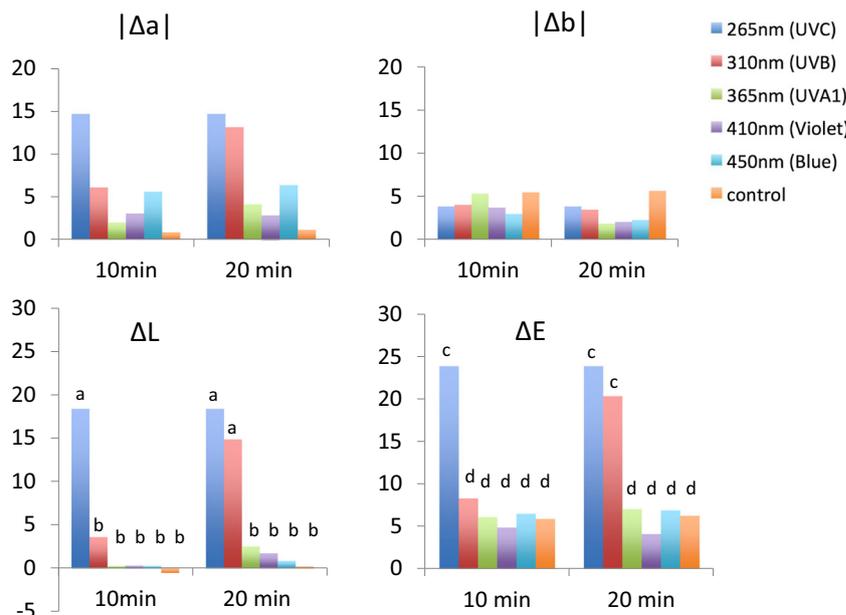
- E* light energy
- h* Plank’s constant
- c* speed of light
- λ wavelength

Consequently shorter wavelengths have greater photon energy and this energy may affect the reaction with hydrogen peroxide. The difference of chromatic alteration of hematoporphyrin paper and the complex tooth will necessitate a prospective study using extracted teeth model. The hematoporphyrin is well absorbed with around 400 nm (blue-violet light) as known Soret band. In this study, 405-nm group did not show specific effect, because intensity of light source might be low. Many bleaching products contain various catalysts and they react the specific wavelength of the light. In this study, 30% HP was used without additives as the only

bleaching agent. Since factors that influence bleaching procedure are comprised of pH, temperature, and catalyst, investigating the interaction of these factors and bleaching effect of UV would be of importance. In fact, the bleaching agent containing the light-activated titanium dioxide photocatalyst could expedite the bleaching process using light irradiation [15]. The catalyst reacted not only with visible light but also with lower wavelength (< 380 nm). Indeed, the absorbance peak of hydrogen peroxide bleaching agent was in UV region (wavelength lower than 380 nm) and gradually decreased with an increased wavelength [13]. Therefore UV light can perform better bleaching results compared to visible light. Further study is necessary to evaluate the effect of UV light on photocatalyst in the bleaching materials.

The amount of hydroxyl radicals is increased followed by UV radiation because hydrogen peroxide absorbs solely UV region, therefore it was expected that UVC source of shortest wavelength delivered highest bleaching results in a short time of 10 min reaching the saturation state. However, UVB of 310 nm proved to be effective when the hematoporphyrin color was almost eliminated after 20 min with the ΔL and ΔE

Fig. 3 The change of ΔL , Δa , Δb , and ΔE . Similar letters indicate no significant difference



slightly less than that of 265 nm, suggestive of the potential for UVB in bleaching lights with or without the combination of other sources.

As far as the safety issue is concerned, ultraviolet light, especially UVB-UVC is harmful for the oral mucosa as well as skin. The penetration of UV in the skin is wavelength-dependent. Longer wavelength (UVA) reaching well deeply into the dermis, while UVB completely absorbed by epidermis, likely producing cellular damage. If the ultraviolet is used for the tooth bleaching, the soft tissues around the target teeth must be protected. UVA and UVB became subjects of research in medical application. UVB phototherapy was offered in dermatology to treat skin eruption (psoriasis) with regulatory mechanisms that minimize misuse of treatment. UVB irradiation induced immunosuppressive reaction thus narrow-band UVB might be useful for treatment of oral mucosal disorder such as periodontitis [16]. The 310-nm UV LED exhibited low toxicity to gingival epithelial cells [17]. Utilization of UV should be controlled regarding output, starting dose and dose increment [18].

Blue and violet LEDs are commonly used for tooth bleaching with wavelength ranging from 400 to 500 nm. Regarding the photobiological effects on pigmentation of wavelengths, blue-violet light (wavelength 415 nm) induced a significantly more pronounced hyperpigmentation that lasted up to 3 months compared to UVB using colorimetric and clinical assessments. However, histological examination showed an increase of keratinocyte necrosis with UVB compared to blue-violet [19]. A prolonged exposure to UV irradiation can result in toxic irritation causing cellular damage and immune suppression, photoaging, and skin cancer [20]. While bleaching products containing UV light have existed in the market, dosage, and duration of use should be of consideration.

LED lights are available across the visible, ultraviolet, and infrared spectrum of wavelength. The LED light system in this study requires low output intensity (Table 1) and generates less heat. LEDs also serve for a longer lifetime and exhibit less degradation of output over time when compared to halogen light [5]. LED produced lowest pulpal temperature rise compared to KTP and diode laser [21]. The temperature increased by increasing the irradiation time for every light-curing unit. The temperature increases were 15 to 60 °C for plasma arc units, around 15 °C for a conventional halogen unit and under 10 °C for LED units [22]. Despite the effectiveness on bleaching, the whitening system Zoom2 containing UV light using mercury metal halide light was reported to produce higher temperature increase compared to femtosecond laser, LED 405 nm wavelength and organic LED [7].

Although a direct comparison between Papalab values with other devices could be impossible, the rank of the color component and ΔE could be similar. The color change in this study ΔE of hematoporphyrin paper is lower compared to

previous work [13] using LED with power density of 835 mW/cm². Laboratory study reported the positive bleaching effect of LED on teeth [21] and it was found that combining with hybrid LED and low-intensity infrared diode laser is more effective than without irradiation [23]. In-office study reported a large difference in bleaching using 35% HP with LED/laser than control group. However, tooth sensitivity after 24-h treatment was observed with higher percentage in subjects exposed to LED group compared to non-irradiation group [24]. Blue and violet LED light curing was more effective than conventional halogen lamp for tooth bleaching with visible light-TiO₂ catalyst [5].

Despite the easy usage, hematoporphyrin paper is sensitive to the light and different from the teeth in terms of color change, which is the limitation of this study. Therefore, the evaluation of UV light in bleaching in clinical cases would be necessary. Furthermore, LED with higher intensity is desirable for usage on teeth to investigate the optimal concentration of bleaching agent, pH, and the exposure time.

Conclusion

Within the limitations of the current study, wavelength of the LED unit affected bleaching effect of 30% hydrogen peroxide using hematoporphyrin-stained paper. While 265 nm showed highest results after 10 min of irradiation, 310-nm wavelength yielded a potential when reaching high bleaching effect after 20 min.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Ethical approval This research does not involve human participants or animals that would necessarily demand informed consent documents or approval of the local ethics committee.

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