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In vitro evaluation of halogen light-activated vs chemically activated in-office bleaching systems

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Abstract

Objectives. To compare the tooth whitening efficacy, temperature and HP concentration changes induced by halogen light-activated and chemically activated in-office bleaching systems. ***Materials and methods.*** Twenty-four extracted premolars were randomly divided into two groups ($n = 12$): Group BL (35% HP with halogen light activation) and Group OP (38% HP with chemical activation). Tooth color was measured by a spectrophotometer according to the CIE L*a*b* color space system. Temperatures of bleaching gels and pulp chambers during the bleaching process were monitored and recorded by a digital multimeter with K-type thermocouple. HP concentrations were tested before and after treatments by iodometry. ANOVA and paired *t*-test were used for statistical analyses at the significance of $p < 0.05$. ***Results.*** Tooth whitening resulted in the increase of ΔL* and ΔE and reduction of Δb*. Paired *t*-tests revealed groups BL had greater ΔE than group OP, however, there was no statistically significant difference in ΔE between them after 3 weeks post-treatment. Maximal temperature rise (ΔT) was found only in group BL, showing the increment of 2.55 and 2.02°C for bleaching gels and pulp chambers, respectively. HP concentrations were higher than baseline values for group OP ($p < 0.001$) rather than group BL. ***Conclusions.*** Halogen light and chemically activated in-office bleaching systems were both effective for tooth whitening, but halogen light activation could improve the immediate whitening effect. In contrast, chemical activation was a more conservative method due to the little temperature rise in pulp chambers.

Key Words: *activation, color, temperature, tooth bleaching*

Introduction

Tooth bleaching has been recognized as a simple, effective and well-accepted method for treating discolored teeth [1,2]. Typically, it can be categorized into three approaches including in-office bleaching, professional at-home bleaching and over-the-counter whitening. In-office bleaching can produce more rapid whitening effects and seems to be an appropriate alternative to the other two techniques when patients have severe discolorations, lack compliance or strongly request an immediate whitening outcome [3].

In-office bleaching has been historically using highly concentrated, 30–35% hydrogen peroxide (HP) [4]. The widely accepted theory is that HP serves as a strong oxidizing agent through the formation of reactive oxygen molecules and per-hydroxyl free radicals [1,5]. Efforts have been made to increase the reaction rate and accelerate the decomposition of HP, including physical activation (heat or light), chemical activation and even dual activation.

Currently, various light sources have been used as a common approach to dissociate HP during in-office bleaching treatment, such as halogen, plasma arc, light emitting diodes (LEDs) and lasers [3,6]. Lights may accelerate the whitening process in terms of photolysis and thermocatalysis. Photolysis of HP can occur by high frequency light with wavelengths of 365 nm or less [7]. Most commercial bleaching lamps emit light falling within the visible spectrum, which may involve little photolysis. When light is projected onto the bleaching agents, a fraction of light can be mainly absorbed and transmitted as heat to degrade peroxide. Therefore, thermocatalysis

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may be considered the main action of light-activated bleaching [3].

Besides light activation, an alternative technology is using chemical activation to enhance the performance of HP. HP is a weak acid and its dissociation can be affected by the pH value of solution or gel [3,8]. An acidic environment makes HP stable for storage, where its decomposition is reduced. In contrast, HP is unstable and easy to decompose under alkaline conditions [9]. Therefore, to increase the pH value is available to activate HP. In addition, the added enzymes (e.g. catalase and peroxidase) or salts of transition metals (e.g. manganese and iron) can promote HP dissociation [10]. In clinical practice, chemical activation is performed by mixing bleaching agent with its activator before using.

Numerous commercial bleaching products with light or chemical activation are widely used in the clinic; however, it seems to be difficult to make the selection. Several studies indicated that bleaching with light was more effective than using agents alone [11–13], whereas others claimed that lights had little-to-no contribution to tooth whitening [3,8,14–19]. Such contradictions may partially result from the different time to assess the efficacy of tooth bleaching [20,21]. Therefore, more comprehensive evidence that consists of quantitative evaluation at different time periods would assist in clarifying of role of light in tooth whitening.

Moreover, pulpal safety is another concern, especially for light-activated bleaching. Since part of the transmitted light through bleaching gels can be partially absorbed by teeth, a temperature rise in teeth or pulp chambers may occur. Zach and Cohen [22] reported that an intra-pulpal temperature rise of 5.5°C led to irreversible pulp damage and an increase of 16.6°C could result in pulpal necrosis. Thus, it is important to investigate the intra-pulpal temperature variation during in-office bleaching process.

The purpose of this study was to evaluate the halogen light-activated and chemically activated in-office bleaching systems, in terms of tooth whitening efficacy, temperature variations in bleaching agents and pulp chambers and HP concentration.

Materials and methods

Tooth selection

The use of extracted human teeth was approved by the Ethics Committee of the School and Hospital of Stomatology, Wuhan University. Twenty-four human maxillary first pre-molars extracted for orthodontic purposes were selected. The teeth were devoid of disease, caries, stain, enamel cracks or fractures or other defects and restorations. The color of selected teeth was A3 or darker. Remaining calculus and soft tissues were removed completely and the teeth were stored in 0.2% thymol at 4°C until use.

Specimen preparation

The apical third of roots were sectioned perpendicular to the long axis of teeth by a low speed saw (Isomet, Buehler Ltd., Lake Bluff, IL) under water cooling. Pulp tissues were removed thoroughly. The canal was enlarged so that a thermocouple wire could be inserted into the pulp chamber from this opening. Then the root stub 2 mm below the cement–enamel junction was individually embedded and fixed in colorless translucent acrylic resin. The radicular entrance of teeth was open for a thermocouple wire. Distilled water was used when the teeth were required to be kept moist in bleaching procedures.

Bleaching procedure

The selected teeth were randomly divided into two groups ($n = 12$):

- Group BL (with halogen light activation): Beyond system.
- Group OP (with chemical activation): Opalescence Boost system.

Details about the two in-office bleaching systems are listed in Table I.

Bleaching treatments were performed twice with a 7-day interval. Each bleaching session contained three cycles of 10 min each. In group BL, the irradiation time was 10 min for each cycle and the distance between the center of the emitting tip of the lamp and buccal surface was set at 10 mm.

Before treatment, the buccal surfaces were polished using a low-speed hand-piece and a rubber cup with fine pumice slurry, rinsed with distilled water and dried by compressed air. The ambient temperature was kept at 25 ± 1°C and the relative humidity was 65%. During the bleaching process, specimens were placed in a thermal water bath (Tri-purpose electro-thermal constant-temperature water tank, Taisite Instrument Co., Tianjin, China) at 37 ± 1°C to enable the temperature of pulp chambers to reach 30 ± 1°C. Bleaching gels were applied on the tooth surface to a thickness of 2 mm.

Color measurement

Tooth color based on the CIE L*a*b* color space system was measured with a spectrophotometer (PR-650 Spectra Scan, Photo Research Inc., Chatsworth, CA) using a D65 illuminant with a 45° entrance angle and 0° observation angle geometry. Prior to measurement, the spectrophotometer was calibrated with a white reflectance standard tile according to the instruction. A circular area with

Table I. Details about two in-office bleaching systems used in this study.

In-office bleaching system	HP %	Color of agents	Other composition	Activation
Beyond (Beyond Technology Corp., Santa Clara, CA)	35% HP, gel	Transparent	No information	Beyond Whitening Accelerator (a halogen lamp, wavelength interval: 390–740 nm)
Opalescence Boost (Ultradent Products Inc., South Jordan, UT)	38% HP, gel	Red	Fluoride, potassium nitrate	Chemical activation

1.0 mm in diameter was measured at the middle third region of buccal surfaces. The custom sample holder was used to position specimens in order to re-orient them at the same place. Mean L*a*b* value of each specimen was determined after three times of measurements. Wet cotton pellets were used to inhibit the surface dehydration.

Color measurements were performed at the following intervals: baseline (T0), the end of the first bleaching procedure (T1), 1 week after the withdrawal of the first bleaching procedure (T2), the end of the second bleaching procedure (T3), 1 week (T4), 2 weeks (T5), 3 weeks (T6) and 4 weeks (T7) after the withdrawal of the second bleaching procedure. The specimens were stored at 37°C in daily replaced artificial saliva [23] between time points.

The differences of L*, a* and b* between baseline (T0) and other time intervals (T1–7) were expressed as ΔL^*, Δa^* and Δb^*.

$$\Delta L^* = L^*_{post} - L^*_{baseline}$$
$$\Delta a^* = a^*_{post} - a^*_{baseline}$$
$$\Delta b^* = b^*_{post} - b^*_{baseline}$$

The overall color difference ΔE for each specimen was obtained by the following formula: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

Temperature measurement

Temperature was recorded by a digital multimeter (MS8226T, Precision MASTECH Enterprises Co., Shenzhen, PR China) with a bead thermocouple of type K (Precision MASTECH Enterprises Co.). The collected data available in tabular and graphic forms were monitored and transferred in real time to a personal computer. The sampling rate of the data-logger software was 1 s per sample for a recording period of 10 min.

Thermocouple-A was inserted into the pulp chamber in labial position and an X-ray was taken to verify its position (Figure 1). Thermocouple-B was immersed in bleaching gels on the middle third of the labial surface (Figure 1). To facilitate heat transfer from the dentin wall to thermocouple-A, the pulp chamber was filled with a heat-transfer silicone (Keda chemical Enterprises Co., Changzhou, PR China). The root opening was then sealed with wax.

Bleaching agent test

Prior to bleaching treatment, the pH values of bleaching gels were measured three times by a digital pH electrode (EASYFERM PLUS 225, Hamilton, Switzerland). HP concentration of bleaching gels used in this study was tested eight times by the method of iodometry [24]. The residual gels on the buccal surface of each specimen were scraped off for testing after treatment.

Statistical analysis

Data were statistically analysed using SPSS 16.0 (SPSS, Chicago, IL) and reported as mean (SD). ΔL^*, Δa^*, Δb^* and ΔE at T1–7 were analysed by one-way repeated measure of ANOVA.

Differences in tooth color, the maximal temperature rise of ΔT (°C) and HP concentrations were compared using paired *t*-test followed by Tukey's

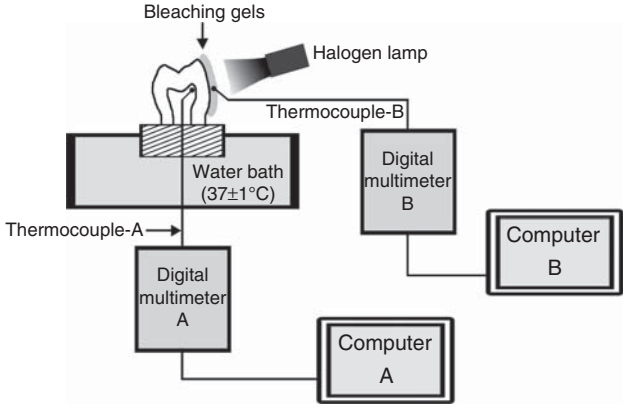

Figure 1. Schematic drawing of experimental set-up showing the temperature measurement during the halogen light-activated bleaching.

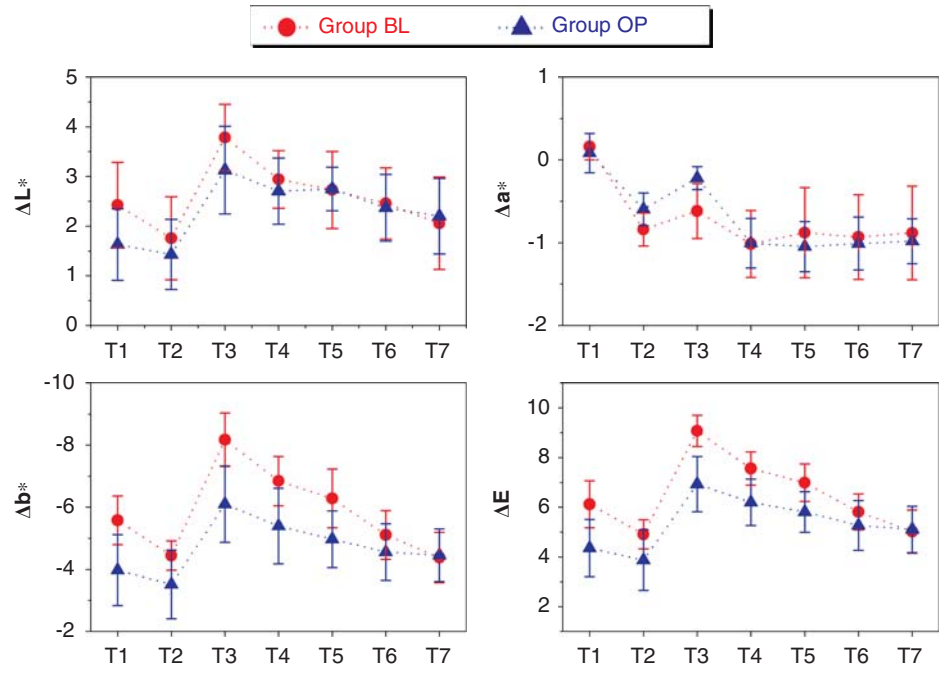

Figure 2. Tooth color change (mean and SD) in each testing interval.

post-hoc test at the significance level of $p < 0.05$. Pearson's correlation coefficient was applied to determine significant correlations between the temperature rise in bleaching gels and pulp chambers.

Results

Color analysis

At baseline, there was no significant color difference between group BL and OP ($p = 0.310$ for L*, $p = 0.391$ for a*, $p = 0.195$ for b*). ΔL*, Δa*, Δb* and ΔE (mean and SD) at each testing interval are shown in Figure 2. The bleaching treatments induced the increase of ΔL* and ΔE and the decrease of Δb*. The maximal value of ΔE was detected at T3. Color relapse was found in each group after treatment, especially in group BL.

The repeated measures ANOVA revealed that ΔE, ΔL*, Δa* and Δb* were influenced by the factor of time (all $p < 0.001$). Tukey's post-hoc comparison results of ΔE are listed in Table II. Significant color changes were found between T3 and other periods. Paired *t*-tests revealed significant differences of ΔE and Δb* between two groups in intervals T1–T5 (all $p < 0.05$), whilst there was no statistically significant difference between T6 and T7 (all $p > 0.05$). No significant difference in ΔL* and Δa* was found between these two groups as well ($p = 0.196$, $p = 0.795$, respectively).

Table II. Results of repeated measure ANOVA and Tukey's multiple comparison test of ΔE in each group.

Groups	*p*-value	Time	Tukey's test						
Group BL	<0.001	T1	a				e	f	
		T2		b					g
		T3			c				
		T4				d			
		T5	a				e		
		T6	a					f	
		T7		b					g
Group OP	<0.001	T1	a						
		T2		b					
		T3			c				
		T4				d			
		T5					e		
		T6						f	
		T7						f	

In each group, different lowercase letters mean statistically significant differences ($p < 0.05$).

Temperature analysis

The representative temperature curves of bleaching gels during the bleaching process for each cycle are shown in Figure 3 and intra-pulpal temperature variations are presented in Figure 4. Mean (SD) of ΔT for bleaching gels and pulp chambers are listed in Table III. A significant temperature rise was found in group BL and there were statistically significant differences of ΔT between the two groups ($p < 0.001$). Moreover, there was a strong and positive correlation between ΔT of bleaching gels and pulp chambers with a Pearson correlation coefficient of 0.943.

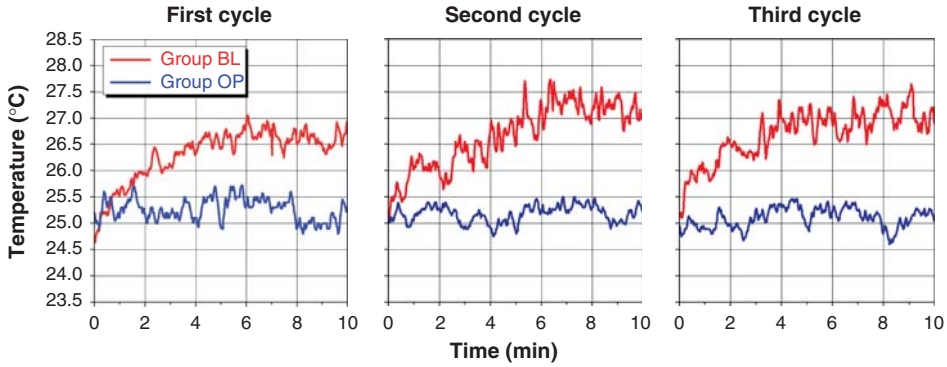

Figure 3. Temperature variation of bleaching gels during in-office bleaching process.

Evaluation of bleaching gels

The mean value of pH for the Beyond system was 4.0 and 7.5 for the Opalescence Boost system immediately after mixing with its activator.

The variations of HP concentration are shown in Figure 5. In group OP, HP concentration after treatment was higher than the baseline value ($p < 0.001$), whilst there was no statistically significant difference in group BL ($p = 0.109$).

Discussion

The present study was conducted to evaluate the tooth whitening efficacy of halogen light-activated and chemically activated in-office bleaching systems, including both immediate and long-term effects. Meaningful results were obtained in this study, indicating that tooth whitening could be achieved by using highly concentrated bleaching agents with light or chemical activation. Moreover, halogen light-activated bleaching was able to enhance the immediate whitening effect. These results were also in agreement with previous studies [11,16,21]. Light-activated bleaching treatment could be of clinical significance in building up patients' confidence and enhancing their motivation and satisfaction.

However, it should be pointed out that there was no significant color difference between group BL and group OP after 3 weeks post-treatment, indicating that light-activated and chemically activated bleaching might have similar effects on the long-term outcomes. In comparison, light-activated bleaching had more color relapse and might not improve the long-term whitening effect. Kugel et al. [18] and Papathanasiou et al. [19] also concluded that light had little influence on tooth whitening over a 2-week observation. Consequently, dentists and patients should not be over-enthusiastic about the long-term whitening effect of light-activated bleaching.

The immediate whitening effect might be related to tooth dehydration, which resulted in a temporary increase in tooth brightness [11,14,20]. Tooth color could become lighter during the dehydration period and rebound during the subsequent rehydration [12,25]. During the in-office bleaching process, tooth dehydration could be caused by various factors, such as desiccation from rubber dam isolation, using non-hydrated whitening gels and heat from adjunct lights [8,14,18,20,25]. Based on the observed temperature rise in group BL (Table III), the enhanced dehydration probably could be a reason for improvement of the immediate whitening effect by light activation.

Regarding light-activated bleaching, the mechanism of light activation was important to explain why the temperature increased in bleaching agents and pulp chambers. It is worth noting that the halogen lamp used in this study emitted visible light ranging

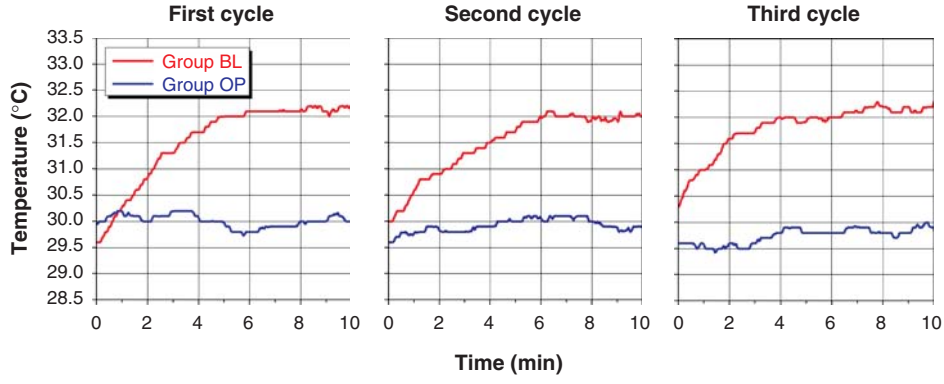

Figure 4. Temperature variation of pulp chambers during in-office bleaching process.

Table III. Means (SD) of maximal temperature rise (ΔT, °C) in bleaching gels and pulp chambers during bleaching treatments.

Groups	Bleaching gels	Pulp chambers
Group BL	2.55 (0.77)*	2.02 (0.21)*
Group OP	0.24 (0.21)	0.20 (0.12)

*Statistically significant differences between group BL and OP ($p < 0.001$).

from 390–740 nm [15], which is higher than the critical value of 365 nm. Accordingly, as this halogen light activation is mainly due to thermocatalysis rather than photolysis, it is mostly used to 'heat' bleaching agents, through the light absorption process of bleaching agents and the transmission of absorbed energy to peroxide [21,26].

In group BL, the bleaching gels were 'heated' by halogen light; however, the HP concentration did not change significantly after treatment. Therefore, the limited heat from light could not be responsible for the dissociation of HP, which was in line with previous studies [8,27,28].

Interestingly enough, in group OP, there was an obvious rise in HP concentration after treatment. This indicated that chemical activation might be more effective to keep the high concentration of HP during the tooth bleaching process compared with halogen light activation. As mentioned above, HP performs very unstably in the alkaline condition. In this study, the bleaching gel of the Beyond system was acidic with a pH value of 4.0, whereas the pH value of the Opalescence Boost system was 7.5 after mixing with activator. Hein et al. [8] evaluated three kinds of in-office bleaching systems with chemical activation and found that the pH value of each bleaching gel increased significantly after its activator was added. Thus, one possible explanation for the concentration rise in group OP was that the activator improved the formation of active radicals by raising the pH value [3,8].

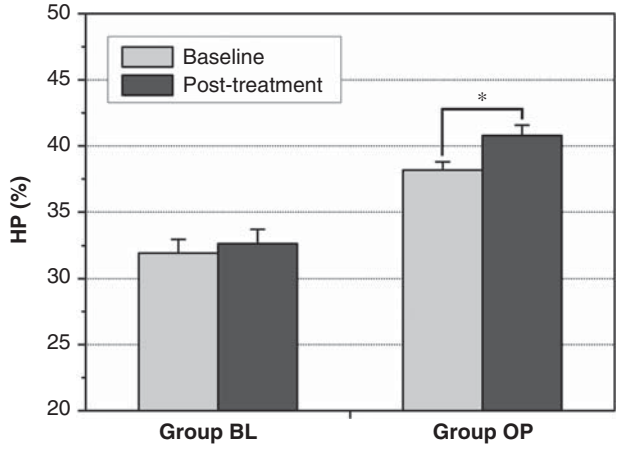

Figure 5. HP concentrations (mean and SD) at baseline and post-treatment.
*Statistically significant differences ($p < 0.001$).

It is worth mentioning that enamel demineralization occurs when the pH value falls below 5.2 [29]. Thus, in this *in vitro* study, Beyond bleaching gel with the pH value of 4.0 might cause the demineralization of the enamel surface and have potential negative effects on chemical structure and composition [2,30,31], mechanical properties [32] and surface morphology [2,31] of enamel. In contrast, our previous studies [2,30,31] indicated that the neutral HP had less deleterious effects on enamel than the acidic one. Accordingly, chemical activation might be useful to decrease the adverse effects of bleaching agents by increasing the pH level.

With respect to pulp safety, the intra-pulpal temperature rise is more clinically relevant, which leads to pulpal response and even pathological alterations of the pulp tissue [33]. The maximal intra-pulpal temperature rise was a critical factor for pulpal health [34]. Under the present testing condition, this halogen light produced a temperature rise of ~ 2°C under the 10-min irradiation, which was lower than the threshold of 5.5°C. Therefore, the increase in intra-pulpal temperature was compatible with pulpal health, although our results showed that the halogen lamp produced a significant increment in pulpal temperature. Encouragingly, no significant intra-pulpal temperature rise was found in group OP and chemical activation induced a safer intra-pulpal temperature rise than light activation. A recommendation for clinicians should be choosing the option that causes a minimum intra-pulpal temperature rise in order to avoid undesired thermal damage of pulp tissues.

Conclusions

With the limitations of this *in vitro* study, the following conclusions were drawn:

- Both halogen light-activated and chemically activated in-office bleaching systems were effective for tooth whitening and an advantage of light-activated in-office bleaching was to improve the immediate whitening effect.
- Chemical activation was a more conservative method due to the lower intra-pulpal temperature rise than halogen light.

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