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Effect of halogen light irradiation on hydrogen peroxide bleaching: an *in vitro* study

S Liang,* Y Sa,* L Sun,* X Ma,* Z Wang,* W Xing,* T Jiang,* Y Wang*

**The State Key Laboratory Breeding Base of Basic Science of Stomatology (Hubei-MOST) and Key Laboratory of Oral Biomedicine Ministry of Education, School and Hospital of Stomatology, Wuhan University, Wuhan, China.*

ABSTRACT

Background: The aim of this study was to evaluate the effect of halogen light irradiation on hydrogen peroxide (HP) bleaching by assessing HP concentrations, tooth whitening efficacy, and temperature variations in bleaching agents and pulp chambers.
Methods: Sixteen premolars were randomly divided into two groups: Group BL (bleaching agent with halogen light irradiation for 3 × 10 minutes) and Group B (bleaching agent alone). HP concentrations were tested before and after treatment. CIE L*a*b* values of specimens were obtained using a spectrophotometer. Temperatures of bleaching gels and pulpal chambers were recorded by a digital multimeter with K-type thermocouple. Data were analysed using ANOVA and paired *t*-test.
Results: After treatment, HP concentration in group BL was slightly higher than that in group B. Paired *t*-tests revealed significant differences of ΔE between groups BL and B in all time intervals except at day 35. The temperature rise of bleaching gels and pulpal chambers in group BL was significantly higher than that in group B.
Conclusions: In-office bleaching was effective for tooth whitening. The involvement of halogen light was beneficial for the immediate whitening effect but had little impact on the long-term whitening effect.

Keywords: Bleaching, hydrogen peroxide, light, pulp chamber, temperature.

Abbreviations and acronyms: ANOVA = analysis of variance; CIE = Commission Internationale de l'Eclairage; HP = hydrogen peroxide; LED = light emitting diodes.

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INTRODUCTION

Tooth bleaching has been regarded as a simple and conservative method for treating discoloured teeth.[1–3] Generally, this technique can be categorized into the following three types: in-office bleaching, at-home bleaching and over-the-counter whitening products.[4] Compared with the other two techniques, in-office bleaching usually utilizes highly concentrated hydrogen peroxide (HP) as the active agent,[5] with the concentration ranging from 17% to 50%.[6] And it is normally recommended for patients who refuse at-home bleaching, lack the compliance, or strongly require immediate whitening effect.[7]

Recently, various light sources such as halogen, plasma arc, light emitting diodes (LEDs) and lasers[8] have been used to accelerate the bleaching process.[9] However, to date, the mechanisms of light activation for dental bleaching are not well documented. Lights may accelerate the release of hydroxyl-radicals from peroxide in two ways: one is photolysis, the other is thermocatalysis.[10] High frequency light may directly excite the decomposition of HP if the light spectrum is in wavelengths of 365 nm or less.[11] However, most commercial bleaching lamps emit light falling within the visible spectrum, and their use may involve little photolysis.[10] When light is projected onto the bleaching agents, a fraction of light may be mainly transmitted as heat to degrade the peroxide after being absorbed by agents.[12,13] Thus, the advantage of using light in tooth bleaching is to 'heat' HP. In other words, thermocatalysis may be the main mechanism of light activation.

Although bleaching lights are widely used in clinics, many clinicians have expressed concerns over their efficacy. Some studies found lights could influence tooth whitening in a positive way,[14–16] whereas

others indicated no additional effect.[10,17–24] Such contrasting views might be caused by different time intervals for shade evaluation.[12,25] Therefore, more comprehensive evidence is required to evaluate light-activated bleaching techniques, especially the immediate whitening effect, long-term whitening effect and colour stability.

Besides whitening efficacy, pulpal safety is another concern when applying bleaching lights. Since a fraction of transmitted light could be partially absorbed by teeth, a temperature rise in teeth or pulp chambers could occur. It has been proved that an intrapulpal temperature increase of 5.5 °C can lead to irreversible pulp damage, and an increase of 16.6 °C could result in pulpal necrosis.[26] Thus, heat generation and temperature rise during the light-activated bleaching process should be further investigated.

The purpose of the present study was to evaluate the effect of halogen light irradiation on in-office bleaching, in terms of HP concentrations, tooth whitening effects, colour stability, and temperature variations in bleaching agents and pulp chambers.

MATERIALS AND METHODS

Tooth selection and specimen preparation

Sixteen intact human maxillary first premolars, extracted for orthodontic purposes, were selected. The teeth were devoid of disease, stains, enamel cracks or fractures, caries, restorations or other defects. The colour of selected teeth was A3 or darker. Remaining calculus and soft tissues were removed, and the teeth were stored in 0.2% thymol at 4 °C until ready for use.

The apical third of roots were sectioned perpendicular to the long axes of teeth with a low-speed saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA) under water cooling. The pulp tissues were removed completely with the enlarged canal and a thermocouple wire was inserted into the pulpal chamber from this opening. Subsequently, the root stub 2 mm below the cemento-enamel junction was individually embedded and fixed in translucent acrylic resin. The radicular entrance was left open for the subsequent insertion of a thermocouple wire. The specimens were stored at 37 °C in artificial saliva which was replaced daily.[27]

Bleaching protocol

The collected teeth were randomly divided into two groups (n = 8) as follows:

Group BL – Beyond II Advanced Formula Whitening Gel (Beyond Technology Corp., CA, USA) irradiated by a halogen lamp (Beyond Whitening Accelerator, Beyond Technology Corp., CA, USA) and Group B – Beyond II Advanced Formula Whitening Gel without light irradiation.

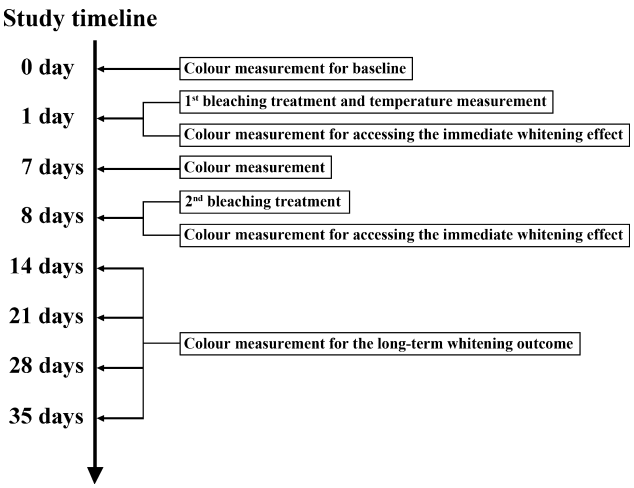

Fig. 1 Flow chart of the present study design.

The design of the present study is presented in Fig. 1. Bleaching treatments were performed twice with a seven-day interval, and each bleaching session contained three cycles with 10 minutes each. For group BL, the irradiation time was 10 minutes for each cycle.

Before bleaching, the buccal surfaces were polished using a low-speed handpiece and a rubber cup with fine pumice slurry, rinsed with distilled water, and dried with compressed air. The ambient temperature was kept at 25 ± 1 °C, and the relative humidity was 65%. During bleaching procedures, 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. The temperature in the pulp chamber was 30 ± 1 °C. Bleaching gels at a thickness of 2 mm were applied to the surface of specimens before light irradiation. The distance between the centre of the emitting tip of the lamp and the buccal surface was set at 10 mm.

Bleaching agent test

The pH values of bleaching gels were measured three times with a digital pH electrode (Easyferm Plus 225, Switzerland), and the mean values were recorded as the final pH. Prior to bleaching, the actual HP concentrations of the bleaching gels were tested eight times using the US Pharmacopeia method of iodometry.[28] The residual gels on the surface of each specimen were scraped off and tested at the end of treatment.

The procedure for measuring HP concentration was as follows: (1) the bleaching gel was weighed using an analytical balance and then placed in a beaker with 100 ml deionized water and 20 ml glacial acetic acid.

The solution was stirred until the bleaching gel was completely dissolved; (2) potassium iodide (2 g) and three drops of ammonium molybdate solution were added sequentially to the above solution (the colour of the solution changed from yellow to dark yellow or orange depending on the HP concentration); (3) the solution was placed in a dark area for a minimum of 10 minutes; (4) sodium thiosulphate solution (0.025 N) was added until the liquid turned pale yellow; (5) 1% starch indicator was added, and then sodium thiosulphate solution (0.025 N) was carefully titrated until the solution turned colourless; (6) HP concentration in the bleaching agents was computed using the following equation: $HP\% = 1.704 \times V \times (0.025/W)$, where W (g) = weight of tested bleaching gels, and V (ml) = total titration amount of sodium thiosulphate solution.

Halogen lamp test

The spectral emission of the Beyond halogen lamp was tested with a spectrophotometer (PR-650 Spectra Scan, Photo Research Inc., CA, USA) within the wavelength range of 380 to 780 nm at 30 cm distance.

Colour measurement

The colour of each specimen based on the CIE L*a*b* colour space system was measured by a spectrophotometer (PR-650 Spectra Scan, Photo Research Inc., CA, USA) using a D65 illuminant with a 45-degree entrance angle and 0-degree observation angle geometry. Before taking measurements, the spectrophotometer was calibrated according to the manufacturer's instructions. A circular area 1.0 mm in diameter was measured at the middle third region of each specimen. The custom sample holder was used to reorient the specimens at the same place. Values of CIE L*a*b* were measured thrice, and the mean value for each specimen was determined. Wet cotton pellets were used to prevent dehydration of samples.

The differences between L*, a* and b* at baseline, as well as other periods after bleaching, were expressed as ΔL*, Δa* and Δb*, respectively.

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

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

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

The overall colour difference ΔE of the specimens was obtained by the following expression: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.[29]

Temperature monitoring

Temperature was recorded using a digital multimeter (MS8226T, Precision Mastech Enterprises Co., Shenzhen, China) with a bead thermocouple of type K (Precision Mastech Enterprises Co., Shenzhen, China) (Fig. 2). 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 used was 1 second per sample for a recording period of 10 minutes.

A heat-transfer silicone (Keda Chemical Enterprises Co., Changzhou, China) was applied to the pulp chamber to facilitate the transfer of heat from the wall of the dentine to the thermocouple. Thermocouple probe-A was immersed in the bleaching gels on the middle third of the labial surface. The thermocouple probe-B was inserted into the pulpal chamber in the labial position, and an X-ray was taken to verify the

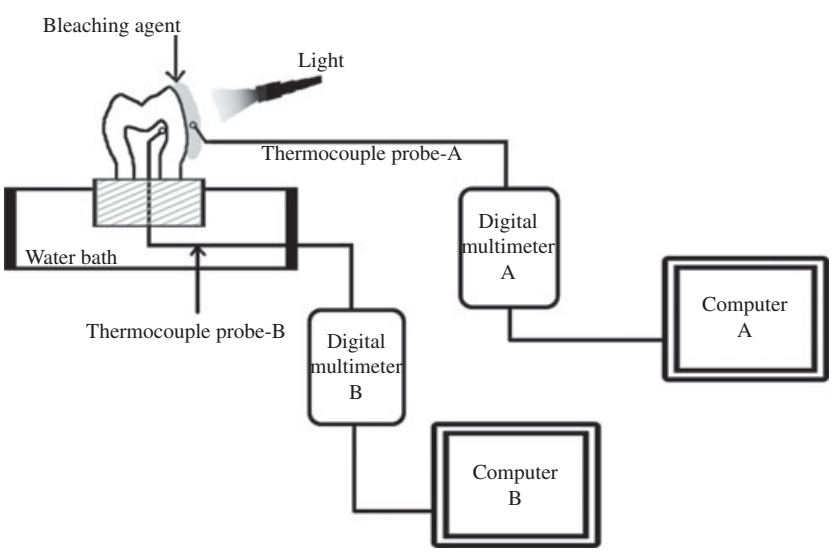

Fig. 2 Schematic drawing of experimental set-up showing the temperature measurement during light-activated bleaching.

position of the thermocouple. The root opening was then sealed with wax.

Statistical analysis

Statistical analyses were performed using SPSS 16.0 (SPSS, Chicago, IL, USA). Descriptive statistics were obtained, and data were reported as mean ± SD. The colour differences in each group were analysed using a one-way repeated measure of analysis of variance (ANOVA) to evaluate the within-group factor (time). Paired *t*-test was used to analyse the colour change values between the two groups. The changes in HP concentration were analysed using one-way ANOVA. The maximal temperature rise (ΔT) was analysed with paired *t*-test and Pearson's correlation test. All analyses were followed by Tukey's *post hoc* test for multiple comparisons ($\alpha = 0.05$).

RESULTS

pH and concentration of bleaching gels

The pH value of activated gels was 4.00 ± 0.05. After bleaching, the mean HP concentration in group BL was slightly higher than that in group B ($p = 0.027$), but they were not different from baseline ($p = 0.278$, $p = 0.497$, respectively) (Fig. 3).

Optical characteristic of the halogen light

The irradiated area of the halogen lamp was 65 mm × 25 mm, and its output ranged from 390 to 740 nm (purple, blue and green), with a major peak at 530 nm (green) and a minor peak at 662 nm (red).

Colour analysis

Colour coordinates (ΔL*, Δa* and Δb*) and ΔE for each testing interval are shown in Fig. 4. The whitening treatments resulted in increased L* and ΔE and decreased b*. After treatment, colour relapse was found in each group, especially in group BL.

One-way repeated measure of ANOVA revealed that ΔE, ΔL*, Δa* and Δb* were significantly influenced by time (all $p < 0.001$). Tukey's *post hoc* comparison results of ΔE are listed in Table 1. The maximal value of ΔE was detected after the second treatment. The two groups had statistically different Δb* and ΔE (all $p < 0.001$), but not for ΔL* and Δa* ($p = 0.435$, $p = 0.135$, respectively). Paired *t*-tests revealed highly significant differences in ΔE between the two groups in all intervals except day 35 ($p = 0.201$ for day 35).

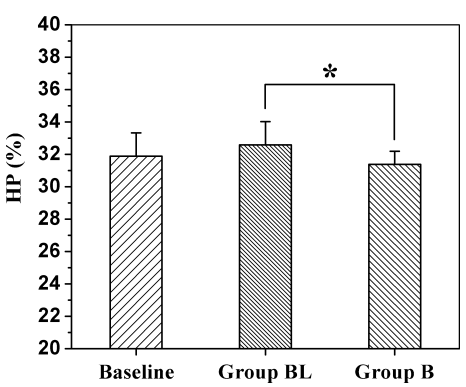

Fig. 3 HP concentration (mean and SD) at baseline and after bleaching treatments. *Statistically significant differences ($p < 0.05$).

Temperature analysis

The representive temperature curves of bleaching gels during treatment for each cycle are shown in Fig. 5, and the intrapulpal temperature variation is given in Fig. 6. ΔT (means ± SD) for bleaching gels and pulpal chambers are described in Table 2. Light irradiation induced a significantly higher temperature increase in both bleaching gels and pulpal chambers ($p < 0.001$). Pearson correlation coefficient of ΔT between bleaching gels and pulpal chambers in each group was 0.831, and the degree of correlation was pole strength.

DISCUSSION

The present study indicated that tooth whitening could be achieved with a highly concentrated bleaching agent with and without light activation. Moreover, in-office bleaching with halogen light irradiation was more effective to improve the immediate tooth whitening than unirradiated treatment. These results were in agreement with previous studies that used different types of light sources.[12,14,19,30] Therefore, from the clinical perspective, bleaching lights may strengthen the confidence and compliance of patients to continue with dental bleaching. However, it should be pointed out that there were no significant colour differences between two groups at four weeks post-treatment. This indicated that light-activated bleaching had greater colour relapse and might not be capable of enhancing long-term whitening effect. Several studies also demonstrated that light had little influence on the tooth whitening response over the two-week observation period.[19,21,23] Therefore, dentists and patients should not be overly enthusiastic about the long-term result of light-activated bleaching treatments.

For light-activated bleaching, the better effect on immediate tooth whitening and greater colour relapse was mainly attributed to the increased dehydration effect. Tooth colour became lighter during the dehydration period and colour rebounded during the subsequent rehydration period.[31] During the

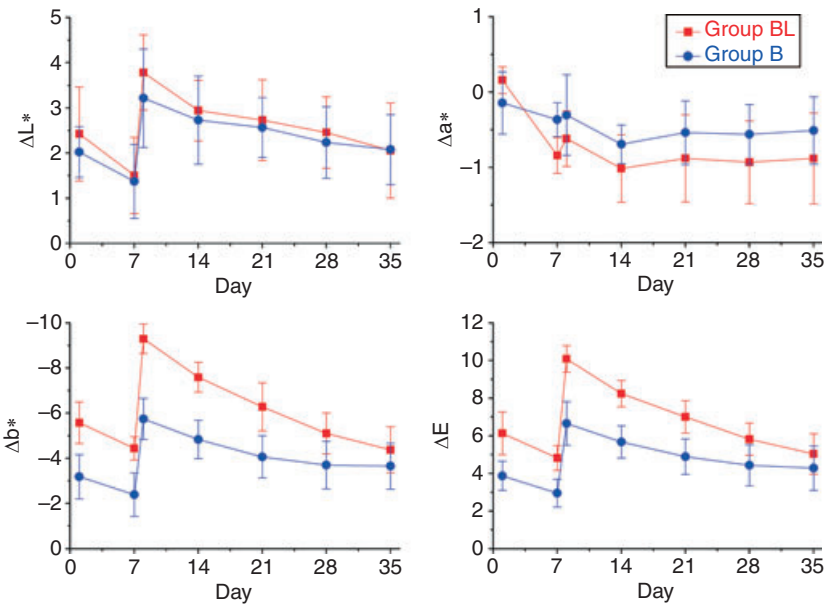

Fig. 4 Tooth colour change (mean and SD) in each testing interval.

Table 1. Results of one-way repeated measure ANOVA and Tukey's multiple comparison test of mean colour difference (ΔE) in each group

Group	*p*-value	Time	Tukey's test						
		1 d	a				e	f	g
		7 d		b				f	g
		8 d			c				
Group BL	<0.001	14 d				d			
		21 d	a				e		
		28 d	a	b				f	
		35 d	a	b					g
		1 d	a						g
		7 d		b					
		8 d			c				
Group B	<0.001	14 d				d			
		21 d					e		
		28 d						f	g
		35 d	a					f	g

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

in-office bleaching process, various factors could lead to tooth dehydration, such as tooth isolation, using non-hydrated whitening gels and heat from supplementary lights.[21,22,31] In this study, the only difference between group BL and group B was the halogen light irradiation. Based on the results of temperature analysis, it could be speculated that light irradiation resulted in higher temperature on the tooth surface, which caused more dehydration. As a result, group BL had a better effect on the immediate tooth whitening but less colour stability.

Light irradiation may induce not only the increased dehydration effect but also the desiccation of bleaching gels. Consequently, the HP concentration of residual gels in group BL was slightly higher than that in group B after treatment. It has been suggested that the efficacy of tooth bleaching was highly associated with concentration.[32] However, light irradiation seemed to have

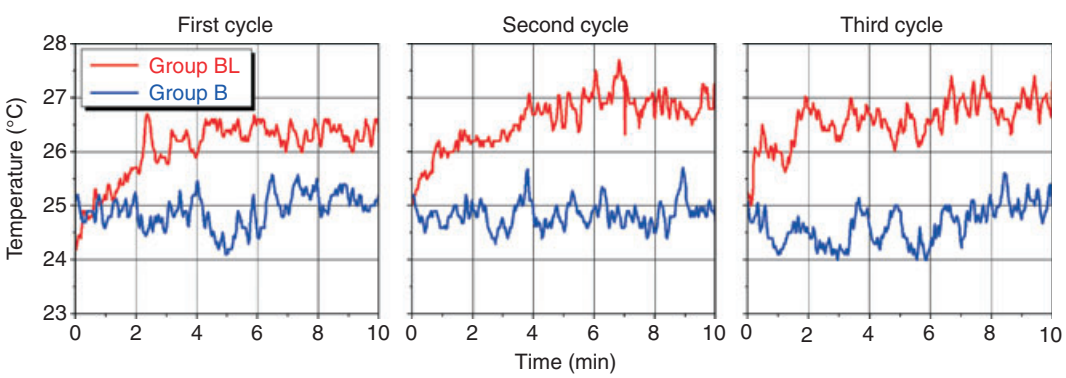

Fig. 5 Temperature variation in bleaching gels during the bleaching process.

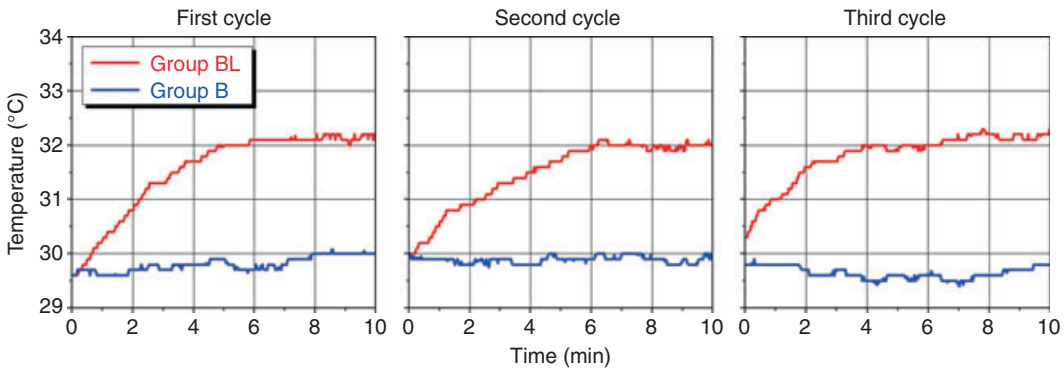

Fig. 6 Temperature variation in the pulpal chamber during the bleaching process.

Table 2. The maximal temperature rise (ΔT, °C) in bleaching gels and pulp chambers during bleaching treatments

Groups	ΔT (means ± SD) in bleaching gels	ΔT (means ± SD) in pulp chambers
Group BL	2.58 ± 0.88*	2.06 ± 0.27*
Group B	0.58 ± 0.60	0.16 ± 0.14

*Statistically significant difference between group BL and group B ($p < 0.001$).

little effect on the long-term bleaching effect, even though it could maintain the high concentration of HP during the bleaching process.

Based on the results presented, the halogen lamp emitted visible light ranging from 390 to 740 nm and this wavelength is higher than the critical value of 365 nm. Therefore, light activation of the halogen lamp is mainly due to thermocatalysis rather than photolysis. This explained why the temperature increased in bleaching agents and pulp chambers.

Besides the temperature rise in the bleaching gels and on the tooth surface, the increase in intrapulpal temperature during the bleaching process is more clinically relevant. Intrapulpal temperature rise leads to pulpal response and even pathological alterations of pulp tissues.[33] The maximal increment of intrapulpal temperature is critical for pulpal health.[34]

In the present study, the halogen lamp produced a temperature rise of approximately 2 °C under the 10 minutes of irradiation, which was below the critical value of 5.5 °C. In previous studies, some bleaching lamps were investigated for intrapulpal temperature changes. The intrapulpal temperature increments were 0.3 °C to 0.8 °C for a plasma arc (Apolite Plasma Arc, 3 seconds), 1.2 °C to 2.1 °C for a xenon-halogen lamp (Luma Arch, 10 minutes), 1.4 °C to 2 °C for a standard halogen lamp (Optilux 501, 30 seconds), and 7 °C to 8 °C for a diode laser lamp (30 seconds).[35] The xenon arc lamp with gels resulted in an intrapulpal temperature rise of 2 °C to 4 °C.[36] Mean maximal intrapulpal temperature rise was 2.95 °C for LED, 3.76 °C for KTP laser, and 7.72 °C for diode laser.[37] Thus, the intrapulpal temperature varied and generally depended on the type of bleaching lamp and irradiation time.

CONCLUSIONS

Based on the results of this study, the following conclusions could be derived: (1) in-office bleaching system, with or without light irradiation, was effective for tooth whitening; and (2) the involvement of halogen light could enhance the immediate whitening effect but have little influence on the long-term whitening effect over the four-week observation period.

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Address for correspondence:
Professor Yining Wang
The State Key Laboratory Breeding Base of
Basic Science of Stomatology (Hubei-MOST)
Key Laboratory of Oral Biomedicine
Ministry of Education
School and Hospital of Stomatology
Wuhan University
237 Luoyu Road
Wuhan 430079
China
Email: wang.yn@whu.edu.cn