

Three-Month Evaluation of Vital Tooth Bleaching Using Light Units—A Randomized Clinical Study

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Clinical Relevance

Light acceleration of the bleaching process, using a laser or halogen light, does not seem to be more beneficial than chemical activation with regard to the stability of tooth color over a period of three months.

SUMMARY

The aim of this study was to evaluate the color stability of vital bleaching using a halogen unit, laser, or only chemical activation up to three months after treatment. A total of 60 patients were divided into three groups, and

their teeth were bleached with 38% hydrogen peroxide using three methods: acceleration of the bleaching process with halogen (eight minutes), laser (30 seconds), or chemical activation only. All teeth were bleached a maximum of four times (4×15 minutes) until a change of six shade tabs took place. The color was evaluated both visually and with a spectrophotometer before bleaching, immediately after bleaching, and one and three months after bleaching. Directly after bleaching, the use of halogen showed better results than laser ($p \leq 0.05$). One and three months after bleaching, no significant difference was found between the tested methods relative to the shade change, independent of the method of shade evaluation ($p > 0.05$). As far as the color stability is concerned, bleaching with halogen resulted in stable color throughout the three months ($p > 0.05$), whereas the other two methods resulted in whiter teeth after one and three months compared with the color directly after bleaching ($p \leq 0.05$). Bleaching with laser needed more time than halogen for the desired

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shade change ($p \leq 0.05$). Although directly after treatment bleaching with halogen resulted in better results, one and three months after bleaching the kind of acceleration used in the bleaching process did not have any effect on the esthetic results.

INTRODUCTION

The esthetics of the smile and teeth, including tooth color, has become of great importance to patients, resulting in increased requests for tooth bleaching. There are several products and methods described for bleaching of vital teeth, including different concentrations of bleaching agents, times of application, application modes, and the kind of acceleration used with the bleaching agent (ie, by means of chemical activation or using light energy).^{1,2} In-office vital tooth bleaching is one of the most popular bleaching methods and is based on the application of 25%-40% hydrogen peroxide products on the external tooth surfaces. The bleaching mechanism is believed to be due to the penetration of hydrogen peroxide into the tooth and the production of free radicals that can oxidize organic stains.^{1,3}

The clinical effectiveness of bleaching has been demonstrated extensively.^{1,4-6} However, it must be mentioned that usually several applications of the bleaching agent are necessary^{7,8} in order to achieve the desired esthetic results. Therefore, the total treatment time needed can be extensive. In order to achieve the same results in a shorter application time, an increase in the efficiency of the bleaching procedure by stimulating the dissociation of the hydrogen peroxide would be helpful. Therefore, recently the use of different light units such as halogen curing lights, LEDs, diode lasers, argon lasers, and plasma arc lamps has been introduced for vital tooth bleaching in order to achieve a better activation of the hydrogen peroxide, resulting in better esthetic results.⁸ However, the *in vitro* findings in the literature concerning the efficacy of using light units for the acceleration of the bleaching agents seem to be controversial.⁹⁻¹³ In previous studies⁹⁻¹¹ it has been shown that bleaching in combination with light units can achieve better results than bleaching with chemical activation. Some other authors^{12,13} have shown that the use of light units for acceleration of the bleaching agent was not beneficial compared with the conventional chemical activation. Even if the efficacy of bleaching agents with light units might be beneficial concerning the acceleration of the bleaching agent and, therefore, the esthetic results achieved after the

bleaching procedure, their use is still questionable concerning the generation of heat by the light sources, with the danger of causing pulp necrosis.⁸ Light-curing units that produce high energy have been shown to result in higher intrapulpal temperature change.¹⁴

Although the efficacy of tooth bleaching with light units has been widely studied *in vitro*,⁶⁻¹¹ only a few *in vivo* studies^{12,15-17} exist concerning the efficacy of vital tooth bleaching by using light units, not giving a clear conclusion about the beneficial use of light acceleration of the bleaching process. Some of these studies^{12,17} showed no difference between bleaching with and without light units, whereas Alomari and others¹⁶ found in their study that the use of light units increase the efficacy of in-office bleaching for a short period of time.

The differences in the bleaching methodologies in the published studies, the controversial results, and the difficulty of a standardized color evaluation make further research in this field necessary. Therefore, the aim of the present study was to evaluate the efficacy of the bleaching with regard to the color stability of an in-office bleaching agent after using a halogen unit or laser compared with bleaching without light units over a period of three months, using two different kinds of color evaluation. The hypothesis made was that all three bleaching methods can achieve the same color change and that the color achieved after the end of the bleaching procedure can remain stable for all methods over the period of three months, independent of the method used for the color evaluation.

MATERIALS AND METHODS

For the present *in vivo* study, 60 volunteers/patients were selected. The study was approved by the Ethics Committee of the University of Freiburg, Freiburg, Germany. All patients treated in the study signed an informed consent form after full explanation of the project. The inclusion criteria were as follows: the participants should be healthy; they should not be pregnant; they should not smoke; their teeth should not have been bleached before; and they should be between 18 and 70 years old. Additionally, the color of the upper canines should be so dark that a change of six tab shades, according to the Vita shade guide (Table 1), could take place. For this purpose, the shade guide tabs were arranged from B1 to C4, corresponding to a grade of whitening from 1 to 16.^{6,18} Any patients with sensitive teeth, caries, or

Table 1: VITA Shade Guide With 16 Shades Ranked From the Lightest Color on the Left to the Darkest Color on the Right

B1	A1	B2	D2	A2	C1	C2	D4	A3	D3	B3	A3,5	B4	C3	A4	C4
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

composite fillings on the upper canines were excluded from the study.

The patients were randomly divided into three groups (n=20). The tested groups were

1. bleaching without using light to accelerate the bleaching process;
2. bleaching with a halogen unit (Beyond Technology Corp, BEYOND European Headquarters, Berlin, Germany); for eight minutes
3. bleaching with a laser unit (KaVo Dental GmbH, Biberach, Germany) for 30 seconds.

Table 2 provides detailed information about the units used for acceleration of the bleaching process. For the bleaching procedure, the same bleaching agent was used for all the tested groups: Opalescence Boost (38% hydrogen peroxide) (Ultradent Products Inc, South Jordan, UT, USA).

Before bleaching, the teeth were polished with a fluoride-free paste. The bleaching procedure took place for a maximum of 60 minutes (4 × 15-minute sessions). After this, the bleaching procedure was terminated even if the change of six shade tabs was not achieved. Additionally, the bleaching procedure was stopped at the onset of sensitivity or pain and the color change achieved at this point was used for the study.

The light sources were applied at the beginning of each bleaching cycle, meaning that each 15-minute cycle was accompanied by the respective light application, according to the group to which it belonged. Therefore, in the case of the group using the halogen unit, it was applied during the first eight

minutes of each 15-minute cycle of the bleaching procedure, and during the remaining seven minutes of each cycle, no light was used. In the case of laser, it was applied for 30 seconds at the beginning of each bleaching cycle.

For the shade evaluation, the color of both canines in the upper jaw was used. The shade change was determined by one examiner with two different techniques: visual evaluation with the VITA shade guide (Table 1); and spectrophotometric evaluation using the tooth vita shade reading from a VITA Easyshade (VITA Zahnfabrik H Rauter GmbH & Co KG, Bad Säckingen, Germany) in the “single tooth shade” mode.

The examiner was previously calibrated for both color selection methods. The shade evaluation took place at the following time periods: before polishing, before bleaching (baseline for evaluation of the bleaching effect), after bleaching, and one and three months after the end of the bleaching procedure. At each tested time point, the visual shade evaluation was performed first and then the digital one.

For each time point, the shade change for each tooth was compared with the baseline. The end of the bleaching procedure was determined according to the shade tab change as identified by the spectrophotometer.

After the bleaching session, patients were advised to avoid the use of red balsamic vinegar, drinking of corrosive drinks, and drinking dark beverages like tea, coffee, red wine, and juices that could stain the teeth for the first three days after bleaching. Oral hygiene instructions included the recommendation

Table 2: Information on the Light Units Used for the Acceleration of the Bleaching Process

Light Units					
Name	Manufacturer	Type	Power output	Wavelength	Application Time
Beyond Whitening Accelerator	Beyond Technology Corp, BEYOND European Headquarters, Berlin, Germany	Halogen	150 W	480–520 nm	8 min
GENTLERay 980	KaVo Dental GmbH, Biberach, Germany	Diode laser	6 W	980 nm	30 s

Table 3: Mean Values of Shade Changes (Δ -Values) \pm Standard Deviations for All Groups and at Each Tested Time Compared With Baseline

Color Change (Δ Mean Values \pm Standard Deviation)					
Bleaching Type	Shade Evaluation	After Tooth Polishing	After Bleaching	1 mo After Bleaching	3 mo After Bleaching
Bleaching without light	Visual	0.0 \pm 0.0	1.75 \pm 2.7	2.9 \pm 2.9	4.55 \pm 1.7
	Digital	0.15 \pm 0.4	4.8 \pm 3.7	7.25 \pm 2.9	7.05 \pm 2.3
Bleaching with laser	Visual	0.15 \pm 0.6	1.15 \pm 1.7	3.65 \pm 2.5	4 \pm 2.17
	Digital	0.05 \pm 0.2	2.15 \pm 2.4	6.75 \pm 3.2	6.7 \pm 2.8
Bleaching with halogen	Visual	0.15 \pm 0.6	5.5 \pm 2.94	4.85 \pm 2.18	4.95 \pm 2.3
	Digital	0.25 \pm 1.1	6.1 \pm 1.9	5.55 \pm 2.2	5.1 \pm 2.1

to use a medium or soft toothbrush and toothpaste with a low abrasive ability for the duration of the study.

Statistical Analysis

A linear mixed model was fitted with a random intercept (subject=patient). The continuous response variable was modeled as a linear function of time, kind of bleaching, the time-group interaction, and the baseline values as explanatory variables, separately for color evaluation. Variance components were used as a covariance structure. Least-square means and pairwise differences were calculated and *p*-values were adjusted by the method of Tukey-Kramer. All calculations were performed with the statistical software SAS system version 9.1 (SAS, Cary, NC, USA) using the PROC MIXED PROCEDURE. The significance level was set at $\alpha=0.05$.

RESULTS

The mean age of the participants in the study was 27.64 ± 5 years. During the bleaching procedure, four patients in the laser group complained of sensitivity/pain. In these cases, the bleaching procedure was terminated and the shade change and bleaching time were used in the study. For these patients, directly after bleaching, two thin layers of Seal & Protect (Dentsply DeTrey GmbH, Konstanz, Germany) were applied on the bleached teeth in order to reduce the sensitivity. These patients were asked to return to the clinic the day after bleaching in order to evaluate the sensitivity. No sensitivity

was present one day after bleaching. No sensitivity was observed after bleaching with the halogen unit or after bleaching without light units. In the present study, no patients were lost and all 60 patients appeared at their recall appointments.

Polishing of the teeth before bleaching did not result in any significant change of color, having no influence on the results of the bleaching methods (Table 3).

The statistical analysis was performed separately for each kind of color evaluation (visual and digital with spectrophotometer). The color changes of each group at each tested time for both types of color evaluation are given in Table 3. The digital evaluation revealed in all cases a greater color shade change compared with the visual evaluation, at each tested time and for all the bleaching methods used. Table 4 provides the results of the pairwise analysis with the Tukey test, comparing the shade change after one and three months with the one after the bleaching procedure, giving important information concerning the stability of the tooth color throughout the study period.

Figures 1–3 illustrate the color change achieved with each bleaching method for both evaluation methods up to three months after the bleaching procedure. Bleaching with halogen showed the greatest shade change directly after bleaching, followed by bleaching without using a light unit and then by bleaching with laser, independent of the color evaluation method. The results at the other two

Table 4: The Pairwise Analysis of the Tested Bleaching Methods at Each Tested Point of Time, According to Tukey-Kramer Test

Tukey-Kramer Test (Adjusted p -Values)*				
Color Evaluation	Pairs Compared	Directly After Bleaching	One mo After Bleaching	Three mo After Bleaching
Visual	Bleaching without light vs bleaching with laser	0.2784	0.9255	0.0578
	Bleaching without light vs bleaching with halogen	0.6610	0.9749	0.1455
	Bleaching with halogen vs bleaching with laser	0.0127	0.9997	0.6455
Digital	Bleaching without light vs bleaching with laser	0.0041	0.8013	0.6267
	Bleaching without light vs bleaching with halogen	0.2047	0.1630	0.1466
	Bleaching with halogen vs bleaching with laser	<0.0001	0.4531	0.1315

* Significance at the level of $\alpha=0.05$.

tested time points differed between the visual and digital evaluation. The digital evaluation showed bleaching without light>laser>halogen at one month and three months after the bleaching, whereas the visual evaluation showed halogen>laser>without light after one month and halogen>without light >laser at three months after the bleaching.

Visual Evaluation

Bleaching Without Light Unit—The time had a significant effect on the color change ($p=0.0035$). At each tested period the teeth were significantly whiter compared with their initial color ($p\leq 0.05$).

The Tukey test showed no significant difference between the color after bleaching and one month later ($p\leq 0.05$), but the tooth color three months after the bleaching was significantly whiter than directly afterward.

Bleaching With Laser—The time had a significant effect on the color change ($p<0.0001$). At each tested period the teeth were significantly whiter compared with their initial color ($p\leq 0.05$). The Tukey test showed that the color one month after the bleaching was significantly whiter ($p\leq 0.05$) than the one right after bleaching, but no further significant change took place during the next two months ($p>0.05$). The color remained stable during the last tested period.

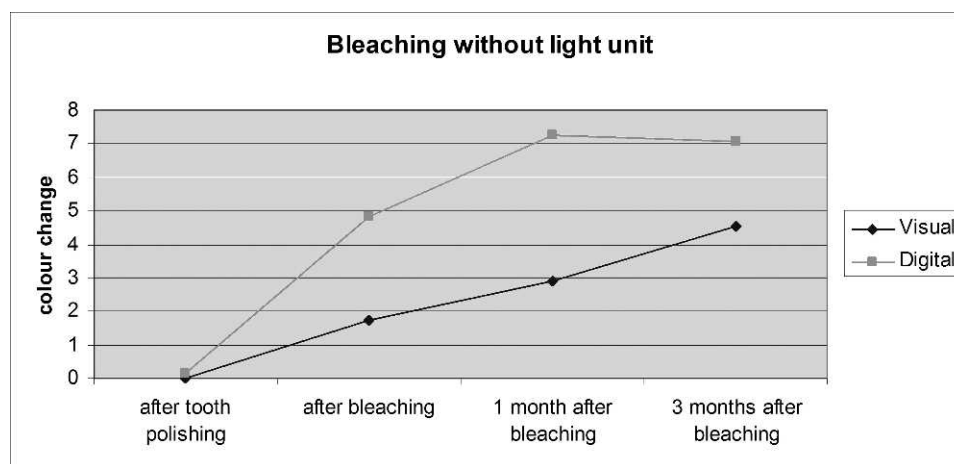


Figure 1. The color change achieved (according to the VITA shade guide) with bleaching without a light unit is presented for both color evaluation methods up to three months after the bleaching procedure.

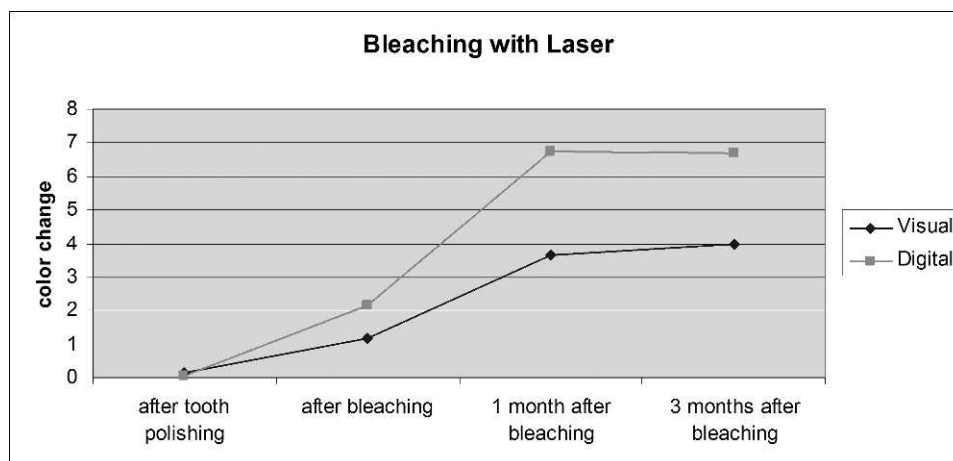


Figure 2. The color change achieved (according to the VITA shade guide) with bleaching with laser is presented for both color evaluation methods up to three months after the bleaching procedure.

Bleaching With Halogen Unit—Although it was shown that separately for each tested time period the teeth were significantly whiter compared with their initial color ($p \leq 0.05$), the statistical analysis showed that generally the time did not affect the color change ($p = 0.6754$). According to the Tukey test, the tooth color remained stable over the three months after the bleaching procedure ($p > 0.05$).

Digital Evaluation

Bleaching Without Light Unit—The time had a significant effect on the color change ($p = 0.0241$). At each tested period the teeth were significantly whiter compared with their initial color ($p \leq 0.05$). The Tukey test showed a significant effect on the tooth color through the first month after the bleaching procedure ($p \leq 0.05$). After this time point,

the color remained stable up to three months after the bleaching.

Bleaching With Laser—The time had a significant effect on the color change ($p < 0.0001$). At each tested period the teeth were significantly whiter compared with their initial color ($p \leq 0.05$). The Tukey test showed a significant effect on the tooth color through the first month after the bleaching procedure ($p \leq 0.05$). After this time point, the color remained stable up to three months after the bleaching.

Bleaching With Halogen Unit—Although it was shown that separately for each tested time period the teeth were significantly whiter compared with their initial color ($p \leq 0.05$), the statistical analysis showed that generally the time did not affect the color change ($p = 0.1710$). This was also supported by the Tukey test.

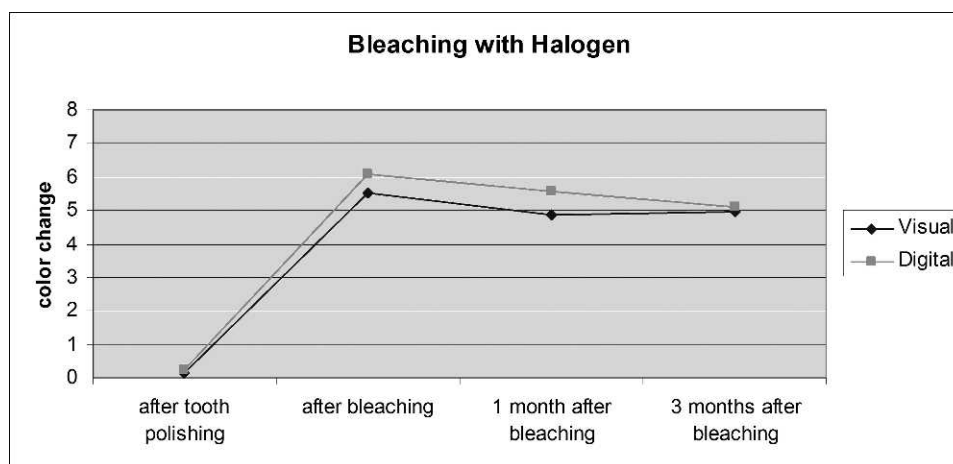


Figure 3. The color change achieved (according to the VITA shade guide) with bleaching with the halogen unit is presented for both color evaluation methods up to three months after the bleaching procedure.

Table 5: The Pairwise Analysis of the Tooth Color at the Different Tested Time Points for Each Bleaching Method

Tukey Test (Adjusted <i>p</i> -Values)*				
Color Evaluation	Pairs Compared	Bleaching Without Light	Bleaching With Laser	Bleaching With Halogen
Visual	After bleaching vs 1 mo	0.3245	0.0016	0.6888
	After bleaching vs 3 mo	0.0024	0.0003	0.7653
	1 mo vs 3 mo	0.1042	0.8657	0.9911
Digital	After bleaching vs 1 mo	0.0363	<0.0001	0.5498
	After bleaching vs 3 mo	0.0592	<0.0001	0.1463
	1 mo vs 3 mo	0.9766	0.9983	0.6689

* Significance at the level of $\alpha=0.05$.

The results of the pairwise analysis of the three bleaching methods tested with the Tukey-Kramer test for each tested time and for both kinds of color evaluation are given in Table 5.

After comparing the three different bleaching methods at each tested time point concerning the shade change, the following were found for the two different methods of color evaluation:

Visual Evaluation—A significant difference was found among the three different bleaching methods directly after the bleaching procedure ($p=0.0011$). At this time point, bleaching with halogen resulted in better results compared with bleaching with laser ($p=0.0127$). One month and three months after the end of bleaching, no significant difference was observed ($p>0.05$).

Digital Evaluation—A significant difference was found among the three different bleaching methods directly after the bleaching procedure ($p<0.0001$). At this time, the Tukey-Kramer test showed that bleaching without a light unit ($p=0.0041$) and bleaching with halogen ($p<0.0001$) resulted in significantly whiter teeth compared with bleaching with laser. One and three months after the end of bleaching, no significant difference was observed ($p>0.05$).

As far as the application time was concerned, a significant difference was found among the three bleaching methods ($p=0.0244$). Longer application time was needed for bleaching with a laser, followed by bleaching without a light unit and then by

bleaching with halogen. However, the pairwise analysis with the Tukey test showed no significant difference between bleaching without a light unit and each of the methods using light acceleration of the bleaching process (laser: $p=0.2288$; halogen: $p=0.5157$). A significant difference was shown between the two groups using a light unit ($p=0.0188$). The application times for the three bleaching methods are given in Table 6.

DISCUSSION

In the present *in vivo* study, three different methods were used for tooth bleaching. For all three methods the same bleaching agent (38% hydrogen peroxide) was used, making the comparison of the three methods easier. Four cycles of bleaching, 15 minutes each, was the maximum bleaching time that took place in the present study, in accord with the study

Table 6: The Bleaching Time of Each Group Needed to Achieve a Whitening of Six Tab Shades

Acceleration Technique	Bleaching Time (min)*
Bleaching without light	48.75 \pm 12.76 ^{ab}
Bleaching with laser	53.25 \pm 12.38 ^a
Bleaching with halogen	45.75 \pm 11.38 ^b

* The use of the same letter does not show any significant difference. Different letter shows significant difference: $p\leq 0.05$.

of Auschill and others,¹⁹ who found that 3.15 cycles of 15 minutes each were necessary in order to achieve the desired six Vita shade-guide tab changes. The mean age of the volunteers who participated in the study was 27.64 years, making the comparison among the tested groups easier. The age of the patients can influence the results of bleaching because the teeth of older patients are more difficult to whiten than those of younger people, due to the different kind of color changes that occur during the maturation stage of the teeth.

In the present study, only bleaching with laser resulted in tooth sensitivity during the bleaching procedure. This is in contrast to the results of Gurgan and others¹⁷ who found similar esthetic results between the groups with and without light acceleration of the bleaching process; however, they found lower tooth and gingiva sensitivity in the case of diode laser. The pulp temperature rise after application of the laser²⁰ in combination with the fact that 30 seconds was used as the application time for the laser treatment might be the reason for the sensitivity mentioned. However, this sensitivity existed only on the first day of bleaching and no further symptoms were observed.

Among the three different test methods, bleaching with the halogen unit showed the best results directly after bleaching, followed by bleaching without a light unit. Bleaching with laser revealed the smallest shade change among the groups directly after bleaching. The two different kinds of color evaluation made it difficult to generalize the present results. According to the digital evaluation, only bleaching with the halogen unit achieved the six-tab change directly after the bleaching procedure. Although no significant difference in esthetic results was found between bleaching with halogen and bleaching without a light unit, bleaching with halogen was more efficient directly after bleaching, whereas bleaching without a light unit achieved better results over time, resulting at the end of the three-month period in a similar color change as that achieved with the halogen unit. This is in agreement with the study of Alomari and others,¹⁶ who found a beneficial effect for bleaching with a blue light-curing unit directly after the bleaching procedure, but they could show that this was only for a short period of time and did not affect the long-term results. However, better esthetic results directly after bleaching would probably be beneficial in daily clinical practice in terms of the patients' satisfaction after the bleaching treatment. Our findings are similar to those of Lima and others¹³ who found in

their study that bleaching in combination with a halogen unit presented the same or higher efficacy than bleaching without using some extra light unit. Not only was the shade-tab change higher in the case of the halogen unit, but additionally the mean time needed to achieve this color change was significantly shorter than the time needed for bleaching with the laser unit. The high power output of the halogen unit used and the presence of the photosensitive agent (beta-carotene) in the bleaching agent might have been the reason for the better results achieved with the halogen unit compared with the laser. The addition of beta-carotene to the bleaching product is supposed to improve its ability to absorb blue light.¹³

Not only the power of radiation but also the wavelength of the laser influences the mechanism of laser systems for bleaching purposes.⁸ The poor esthetic results observed in the group treated with laser compared with that treated with the halogen unit might be due to the wavelength of the laser, which is, at 980 nm, far greater than the 400–500 nm at which the beta-carotene strongly absorbs. The wavelength of the halogen unit is better suited to the absorption spectrum of the beta-carotene. This could explain the results of the present study concerning the difference between the two tested light units. Although it can be considered that the use of a diode laser with another wavelength might have resulted in better results, the fact that diode lasers with a wavelength of 980 nm are among the lasers recommended by the Food and Drug Administration^{21,22} for tooth bleaching makes the situation tested in the present study clinically relevant because no exact information is given for dental clinicians concerning the appropriate combination of bleaching product and laser unit. The combination of bleaching products containing beta-carotene with lasers with high wavelengths is often seen in the literature.^{23–25}

Between bleaching with halogen and bleaching without using some light unit, similar application times were necessary in order to achieve similar esthetic results, according to the statistical analysis. Although the acceleration of the bleaching process with the halogen unit showed good esthetic results directly after bleaching, the fact that the pulp temperature rose during bleaching with a light unit²⁰ makes chemical activation of the bleaching agent more attractive for daily clinical practice.

In the present study, the laser showed the poorest results directly after bleaching especially in comparison to bleaching with the halogen unit. In the study

of Gontijo and others,²⁶ no significant difference was found between bleaching with laser and bleaching with a halogen unit after treating teeth that had undergone root canals. Kashima-Tanaka and others²⁷ showed in their study that the amounts of hydroxide that were generated from the hydrogen peroxide were higher in the case of bleaching by using a plasma arc lamp and halogen unit than by using a laser. However, the different methodologies used among the published studies make their comparison very difficult. Additionally, the light units used among the studies were never the same, making such a comparison very critical. Not all halogen units had the same power output and not all the lasers used in the studies for acceleration of the bleaching process had the same characteristics.

In our study, additional color evaluations took place one and three months after the end of the bleaching procedure. The stability over time of tooth color after bleaching is one of the major concerns of patients after the end of the bleaching treatment. The esthetic results achieved with bleaching accelerated with the halogen unit remained stable over the three months. In contrast to this, bleaching without a light unit and acceleration with the laser resulted in whiter teeth after one month and three months compared with the color achieved directly after bleaching. Therefore, the hypothesis made at the beginning of the study concerning the whitening efficacy of the three bleaching methods and the color stability cannot be accepted.

Our results are in contrast to previous studies^{3,12,13,28} that showed a decrease of the color change and darker teeth some time after the bleaching procedures compared with the results achieved directly after bleaching. Wiegand and others³ found that over a period of 12 months the teeth darkened, but they did not return to the baseline color. In the study of Lima and others,¹³ one month after bleaching a color regression was observed; whereas, in the study of Marsio and others,¹² the same results were found after observation of six months. In an older study of Rosenstiel and others,²⁸ the color regression was seen even seven days after the end of bleaching. These authors^{12,13,28} suggested that the single bleaching treatment used might be responsible for the color regression, and multiple treatment sessions were recommended. Alomari and others¹⁶ found that the use of light acceleration of the bleaching agents increased their efficacy only for a short period of time and did not affect the long-term results of the bleaching agents.

A reversible tooth dehydration was thought^{14,29,30} to be the reason for the whitening effect of the light on the bleaching efficacy. This could not be confirmed in the present study. The esthetic results remained stable or were enhanced over time.

Given the hypothesis of Greenwall³¹ that during bleaching the tooth is filled with oxygen and is dehydrated from the oxidative process, changing the optical qualities of the tooth might offer some explanation of further whitening effect observed in the present study after one and three months. According to Greenwall,³¹ after a period of two weeks the oxygen had dissipated and the rehydrated tooth demonstrated the actual lightened effect.

An additional parameter that might have influenced the results of the present study was the viscosity of the bleaching agent used. Opalescence Boost with 38% hydrogen has replaced last year's version of the bleaching agent Opalescence Xtra Boost with the same concentration of hydrogen peroxide. Although no chemical changes have been reported to take place according to the manufacturer, the texture and the consistency of the bleaching agent differs from that of the previous product; it is more viscous than before. The composition and the viscosity of the bleaching agent have an effect on the diffusion of the hydrogen peroxide and, therefore, on the bleaching procedure.³²⁻³⁴ Bleaching agents with high viscosity show a higher peroxide diffusion compared with less viscous materials.³⁴ This change in the viscosity of the bleaching agent might be responsible for the different behavior during and particularly after the bleaching procedure because the viscosity of the material influences the peroxide-release kinetics.

One important point of the present study was the comparison of the visual color estimation with the digital one. First the visual shade was determined, and then the digital evaluation took place. Tooth color evaluation in daily clinical practice is of great importance for the esthetic result of any dental treatment. It is rather difficult due to several parameters that can influence color estimation, such as daylight, time of the day, and the color of the patient's clothes. The use of a device for the tooth color evaluation can make the daily dental practice easier. Several devices, such as spectrophotometers or cameras, have been marketed for this purpose. It has been mentioned that a spectrophotometer generates a highly accurate spectral curve indicating the exact $L^*a^*b^*$ values.³⁵ The Commission international de l'éclairage (CIE) 1976 $L^*a^*b^*$ system is adequately related to human eye color

perception in all three dimensions of color space.³⁶ The L^* values depict the sample lightness, whereas the a^* and b^* values depict the chroma of the samples. The a^* values are a measure of redness (positive a^*) or greenness (negative a^*). The b^* value is a measure of yellowness (positive b^*) or blueness (negative b^*). The a^* and b^* values approach zero for neutral colors (white, grays). Unfortunately, there are some disadvantages associated with the use of spectrophotometry-based instruments.³⁵ Fogging of the optical device can occur, which can lead to inaccurate readings. There are properties of teeth that complicate the use of spectrophotometers. Translucency, an inherent property of teeth, is abstract and intangible and is currently difficult to measure and standardize. Furthermore, the curved surface of the tooth may be problematic because it might negatively impact the uniform reflectance of light to the spectrophotometer. Translucency can be measured when using a spheric optical spectrophotometer designed for industry and research that captures light reflectance from an object in three dimensions. However, this type of instrument is not designed for clinical use because the object to be measured must be placed within the chamber of the spectrophotometer. According to Lath and others,³⁷ an image system is a reliable alternative measurement method validated against spectrophotometry for stain removal *in vitro* and can provide full color measurement. However, digital evaluation has not been so widely tested as the spectrophotometer. In the present study, the Vita Easyshade intraoral dental spectrophotometer was used. According to the manufacturer, it is a self-contained, portable, digital shade-matching device that is compatible with the 26 Vita System 3D-Master shades, the three Vita System 3D-Master Bleaching shades, and the 16 Vitapan Classical shades. In the literature, the same spectrophotometer has been used in several studies^{12,38–41} over the years to evaluate tooth color. Meireles and others⁴¹ evaluated in their study the validity and reliability of the visual assessment of tooth color using the same spectrophotometer used in the present study. In their study, the Vita Easyshade was used as the criterion standard. The sensitivity and specificity of the visual assessment with respect to the criterion standard was 86.9% and 81.9%, respectively, leading to the conclusion that the visual assessment of tooth color using the VITA Classical shade guide is a valid method with good reliability. In the present study, the visual evaluation of the tooth color resulted in darker colors compared with the digital evaluation. As shown in Figures 1–3, only in the

case of the halogen unit did the visual and digital evaluation seem to show the same color tab change. Although the estimation of the absolute color differed between the two kinds of evaluation for the other two bleaching methods, the statistical analysis revealed the same results for bleaching with laser concerning the color change to the end of the three-month period. As far as bleaching without any light unit is concerned, the results differed among visual estimation and spectrophotometer, and only those for the three-month period showed similar statistical results. Additionally, these two different kinds of shade evaluation revealed the same statistical results for the one-month and three-month observation. Only directly after bleaching were the different kinds of color evaluation found to result in different conclusions. Therefore, according to the findings of the present study the use of a spectrophotometer seems to be more objective concerning the observation of tooth color, and, therefore, the hypothesis made at the beginning of the study concerning the two different methods for color evaluation cannot be accepted. Additionally, the fact that the visual observation revealed darker values compared with the spectrophotometer leads to the hypothesis that human observations seem to be more critical concerning the esthetic results of tooth bleaching.

CONCLUSIONS

Within the limitations of the present study, bleaching with the halogen unit showed a better whitening effect directly after bleaching compared with bleaching with the laser. Bleaching with the halogen unit was not beneficial compared with chemical activation of the bleaching agent. The whitening effect after bleaching with a laser or bleaching without any light unit increased during one and three months compared with the results achieved directly after bleaching. After a period of three months, the esthetic results achieved were similar for all tested bleaching methods. Therefore, it can be concluded that the use of light to accelerate the process of bleaching is not important for esthetic results with regard to long-term whitening effects.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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REFERENCES

- Joiner A (2006) The bleaching of teeth: A review of the literature *Journal of Dentistry* **34**(7) 412-419.
- Joiner A (2007) Review of the effects of peroxide on enamel and dentine properties *Journal of Dentistry* **35**(12) 889-896.
- Wiegand A, Drebenstedt S, Roos M, Magalhães AC, & Attin T (2008) 12-month color stability of enamel, dentine, and enamel-dentine samples after bleaching *Clinical Oral Investigations* **12**(4) 303-310.
- Giachetti L, Bertini F, Bambi C, Nieri M, & Russo DS (2010) A randomized clinical trial comparing at-home and in-office tooth whitening techniques: A nine-month follow-up *Journal of the American Dental Association* **141**(11) 1357-1364.
- Bizhang M, Chun YH, Damerau K, Singh P, Raab WH, & Zimmer S (2009) Comparative clinical study of the effectiveness of three different bleaching methods *Operative Dentistry* **34**(6) 635-641.
- Polydorou O, Hellwig E, & Hahn P (2008) The efficacy of three different in-office bleaching systems and their effect on enamel microhardness *Operative Dentistry* **33**(5) 579-586.
- Al Shethri S, Matis BA, Cochran MA, Zekonis R, & Stropes M (2003) A clinical evaluation of two in-office bleaching products *Operative Dentistry* **28**(5) 488-495.
- Buchalla W, & Attin T (2007) External bleaching therapy with activation by heat, light, or laser—A systematic review *Dental Materials* **23**(5) 586-596.
- Torres CR, Barcellos DC, Batista GR, Borges AB, Cassiano KV, & Pucci CR (2011) Assessment of the effectiveness of light-emitting diode and diode laser hybrid light sources to intensify dental bleaching treatment *Acta Odontologica Scandinavica* **69**(3) 176-181.
- Domínguez A, García JA, Costela A, & Gómez C (2011) Influence of the light source and bleaching gel on the efficacy of the tooth whitening process *Photomedicine and Laser Surgery* **29**(1) 53-59.
- Luk K, Tam L, & Hubert M (2004) Effect of light energy on peroxide tooth bleaching *Journal of the American Dental Association* **135**(2) 194-201.
- Marson FC, Sensi LG, Vieira LC, & Araújo E (2008) Clinical evaluation of in-office dental bleaching treatments with and without the use of light-activation sources *Operative Dentistry* **33**(1) 15-22.
- Lima DA, Aguiar FH, Liporoni PC, Munin E, Ambrosano GM, & Lovadino JR (2009) *In vitro* evaluation of the effectiveness of bleaching agents activated by different light sources *International Journal of Prosthodontics* **18**(3) 249-254.
- Weerakoon AT, Meyers IA, Symons AL, & Walsh LJ (2002) Pulpal heat changes with newly developed resin photopolymerisation systems *Australian Endodontic Journal* **28**(3) 108-111.
- Calatayud JO, Calatayud CO, Zaccagnini AO, & Box MJ (2010) Clinical efficacy of a bleaching system based on hydrogen peroxide with or without light activation *European Journal of Esthetic Dentistry* **5**(2) 216-224.
- Alomari Q, & El Daraa E (2010) A randomized clinical trial of in-office dental bleaching with or without light activation *Journal of Contemporary Dental Practice* **11**(1) E017-E024.
- Gurgan S, Cakir FY, & Yazici E (2010) Different light-activated in-office bleaching systems: A clinical evaluation *Lasers in Medical Science* **25**(6) 817-822.
- Leonard RH Jr, Bentley C, Eagle JC, Garland GE, Knight MC, & Phillips C (2001) Nightguard vital bleaching: A long-term study on efficacy, shade retention, side effects, and patients' perceptions *Journal of Esthetic and Restorative Dentistry* **13**(6) 357-369.
- Auschill TM, Hellwig E, Schmidale S, Sculean A, & Arweiler NB (2005) Efficacy, side-effects and patients' acceptance of different bleaching techniques (OTC, in-office, at-home). *Operative Dentistry* **30**(2) 156-163.
- Eldeniz AU, Usumez A, Usumez S, & Ozturk N (2005) Pulpal temperature rise during light-activated bleaching *Journal of Biomedical Materials Research. Part B, Applied Biomaterials* **72**(2) 254-259.
- ADA Council on Scientific Affairs (1998) Laser-assisted bleaching: An update *Journal of the American Dental Association* **129**(10) 1484-1487.
- Sun G (2000) The role of lasers in cosmetic dentistry *Dental Clinics of North America* **44**(4) 831-850.
- Wetter NU, Walverde D, Kato IT, & Eduardo Cde P (2004) Bleaching efficacy of whitening agents activated by xenon lamp and 960-nm diode radiation *Photomedicine and Laser Surgery* **22**(6) 489-493.
- Goharkhay K, Schoop U, Wernisch J, Hartl S, De Moor R, & Moritz A (2009) Frequency doubled neodymium:yttrium-aluminum-garnet and diode laser-activated power bleaching—pH, environmental scanning electron microscopy, and colorimetric *in vitro* evaluations *Lasers in Medical Science* **24**(3) 339-346.
- Dostalova T, Jelinkova H, Housova D, Sulc J, Nemec M, Miyagi M, Brugnara Junior A, & Zanin F (2004) Diode laser-activated bleaching *Brazilian Dental Journal* **15**(Special Issue) 3-8.
- Gontijo IT, Navarro RS, Ciamponi AL, & Zezell DM (2008) Whitening techniques using the diode laser and halogen lamp in human devitalized primary teeth *Journal of Dentistry for Children* **75**(2) 164-167.
- Kashima-Tanaka M, Tsujimoto Y, Kawamoto K, Senda N, Ito K, & Yamazaki M (2003) Generation of free radicals and/or active oxygen by light or laser irradiation of hydrogen peroxide or sodium hypochlorite *Journal of Endodontics* **29**(2) 141-143.
- Rosenstiel SF, Gegauff AG, McCafferty RJ, & Johnston WM (1991) *In vitro* tooth color change with repeated bleaching *Quintessence International* **22**(1) 7-12.
- Jones AH, Diaz-Arnold AM, Vargas MA, & Cobb DS (1999) Colorimetric assessment of laser and home bleaching techniques *Journal of Esthetic Dentistry* **11**(2) 87-94.
- Amengual Lorenzo J, Cabanes Gumbau G, Cervera Sánchez C, Forner Navarro L, & Llena Puy MC (1996) Clinical study of a halogen light-activated bleaching agent in nonvital teeth: Case reports *Quintessence International* **27**(6) 383-388.

31. Greenwall L (2001) *Bleaching Techniques in Restorative Dentistry* Martin Duntz Ltd, London.
32. Hannig C, Weinhold HC, Becker K, & Attin T (2011) Diffusion of peroxides through dentine *in vitro* with and without prior use of a desensitizing varnish *Clinical Oral Investigations* **15(6)** 863-868.
33. Hannig C, Zech R, Henze E, Dreier S, & Attin T (2005) Peroxide release into saliva from five different home bleaching systems *in vivo* *American Journal of Dentistry* **18(1)** 13-18.
34. Thitinanthapan W, Satamanont P, & Vongsavan N (1999) *In vitro* penetration of the pulp chamber by three brands of carbamide peroxide *Journal of Esthetic Dentistry* **11(5)** 259-264.
35. Chu SJ (2003) Use of a reflectance spectrophotometer in evaluating shade change resulting from tooth-whitening products *Journal of Esthetic and Restorative Dentistry* **15(Supplement 1)** S42-S48.
36. Dietschi D, Rossier S, & Krejci I (2006) *In vitro* colorimetric evaluation of various bleaching methods and protocols *Quintessence International* **37(7)** 515-526.
37. Lath DL, Johnson C, Smith RN, & Brook AH (2006) Measurement of stain removal *in vitro*: A comparison of two instrumental methods *International Journal of Dental Hygiene* **4(3)** 129-132.
38. DA Costa J, Lubisich E, Ferracane J, & Hilton T (2011) Comparison of efficacy of an in-office whitening system used with and without a whitening priming agent *Journal of Esthetic and Restorative Dentistry* **23(2)** 97-104.
39. Scaminaci Russo D, Viano M, Bambi C, Nieri M, & Giachetti L (2010) Color stability of bleached teeth over time: An *in vitro* study *European Journal of Esthetic Dentistry* **5(3)** 300-310.
40. Hassel AJ, Cevirgen E, Balke Z, & Rammelsberg P (2009) Intraexaminer reliability of measurement of tooth color by spectrophotometry *Quintessence International* **40(5)** 421-426.
41. Meireles SS, Demarco FF, dos Santos Ida S, Dumith Sde C, & Bona AD (2008) Validation and reliability of visual assessment with a shade guide for tooth-color classification *Operative Dentistry* **33(2)** 121-126.