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Laser-enhanced tooth bleaching with Nd:YAG, Er:YAG, and diode lasers: an *in vitro* study

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ABSTRACT

Tooth discoloration and staining are aesthetic issues that trouble many patients. The purpose of this study is to compare tooth color change after bleaching with Nd:YAG, Er:YAG, and diode lasers. Forty-eight upper and lower human anterior teeth and premolars were divided into four groups (12 teeth each). Bleaching gel with 38% hydrogen peroxide was placed on the teeth in all four groups. In the first, second, and third groups, Nd:YAG laser, Er:YAG laser, and diode laser were irradiated after applying the bleaching gel. In the fourth group, which is considered as control group, no laser rays were irradiated for activation after the bleaching gel was placed. Before and after bleaching, the shade of the teeth was measured using the CIELab system by a spectrophotometer (SpectroShade, MHT, Verona, Italy). The results were analyzed using one-way ANOVA and Tukey's multiple comparison test. All bleaching methods resulted in significant changes in tooth shade ($\Delta E \geq 3.3$). The average color changes between groups differed significantly ($p<0.05$). Diode laser caused the highest ($\Delta E=10.16$), and Er:YAG laser caused the lowest amount of color change among all groups ($\Delta E=5.14$). There was no difference between the Nd:YAG and Er:YAG lasers ($p>0.05$). The color change in the diode laser group was significantly higher than in the control group, whereas it was lower in the Er:YAG and Nd:YAG groups.

Key words: tooth bleaching; diode laser; Nd:YAG laser; Er:YAG laser; color change; spectrophotometry.

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Introduction

Having white teeth is highly desired by patients and plays a significant role in the aesthetic appeal of their smiles.[1-3] Tooth discoloration and staining are cosmetic issues that trouble many patients. In comparison to veneers and crown restorations, bleaching is a conservative and non-invasive option for treating dental stains. It is a widespread technique for treating internal tooth discoloration and achieving whiter teeth.[4-6] In addition to being non-invasive, this method is also effective, safe, and affordable.[1-3] There are two main types of discoloration: external color change and internal color change. External discoloration affects the outer surface of the tooth (enamel) and is associated with environmental factors or individual behaviors such as tobacco use, highly pigmented food and beverage consumption, and poor oral hygiene.[7-9] Internal discoloration affects the tooth dentin and can be caused by genetic disorders or local factors during or after tooth eruption. Contributing factors also include aging, use of certain antibiotics such as tetracycline during childhood, dental caries, amalgam restorations, bleeding and pulp necrosis, as well as the long-term use of antiseptic mouthwashes like chlorhexidine.[10-15]

However, tooth bleaching mostly targets internal discolorations that cannot be removed through procedures such as debridement or prophylaxis in the dental office.[11] Therefore, in-office bleaching using high concentrations of hydrogen peroxide can quickly fulfill patients' aesthetic expectations. Hydrogen peroxide can penetrate the tooth structure and produce free radicals that oxidize colored organic molecules.[16,17] This reaction can be accelerated under photochemical reactions initiated by light or laser.[18] When patients ask for treatment in one visit, the various types of activating sources could be used to increase the speed of the bleaching process.[19,20] Recently, bleaching has been considered an ideal treatment option due to its shorter working time and less post-operative sensitivity.[21,22] In bleaching process, the photothermal interactions between light and the tooth-whitening agent accelerate the conversion of hydrogen peroxide into highly reactive free radicals that react with pigments and intensify the bleaching process.[7] Nevertheless, it is a fact that tooth bleaching systems could have a negative effect on hard and soft tissues. Therefore, laser bleaching offers more compatibility with these surfaces than other bleaching systems.[23,24]

Different types of lasers are used in laser bleaching, such as CO_2 (carbon dioxide), KTP (potassium titanyl phosphate), argon, Er:YAG (erbium: yttrium-aluminum-garnet), Nd:YAG (neodymium: yttrium-aluminum-garnet) and diode.[25,26] The Food and Drug Administration (FDA) has approved the use of argon, CO_2, and diode lasers for tooth bleaching.[27,28]

The LightWalker laser (Fotona, Ljubljana, Slovenia) is equipped with two separate wavelengths, including Er:YAG laser (2940 nm) and Nd:YAG laser (1064 nm). The Er:YAG laser's wavelength is near the water absorption peak, allowing most of the energy to be absorbed by the gel for heating, which minimizes damage to the hard tissue of the teeth and makes the procedure safe and minimally invasive. As a result, this method can be performed with minimal adverse thermal load on the tooth and safely increase the tooth bleaching speed.[25-27,29,30]

Diode lasers operating within the wavelength range of 810-980 nm serve as both activators and enhancers for bleaching gels. The energy emitted by the laser elevates the temperature of the bleaching agent, thereby accelerating the chemical reactions associated with the bleaching process and improving its efficacy. This can result in a more effective decomposition of chromogenic compounds and a faster whitening effect by diode lasers.[31]

The Nd:YAG laser has great potential for teeth bleaching because it generates enough heat to activate and decompose hydrogen peroxide. Also, studies conducted on Nd:YAG laser have reported chemical changes in tooth structure, increased distribution of calcium, phosphorus, magnesium, and oxygen in tooth enamel, and its resistance to acid.[32]

Despite the popularity of laser bleaching, there is limited information about its effectiveness when using different wavelengths of diode lasers, Er:YAG. and Nd:YAG lasers.[19,20]

The purpose of this study is to compare tooth color change after bleaching with Nd:YAG, Er:YAG, and diode lasers.

Materials and Methods

This article is based on a student thesis, which has been approved by the Ethics Council in Research at Alborz University of Medical Sciences under the code IR.ABZUMS.REC.1402.251.

For this comprehensive *in vitro* study, we extracted a sample of healthy human anterior and premolar teeth that were extracted for periodontal or orthodontic reasons from our research population. To ensure adequate representation, we included 12 teeth in each group. Our inclusion criteria required that teeth have intact enamel on their incisal, canine, or premolar cusps. We excluded any teeth with caries lesions, visible cracks, hypoplastic lesions, or severe color changes within the tooth. After selecting our sample, we removed any remaining soft tissue and debris from the teeth using an ultrasonic scaler. Then, we soaked the teeth in a 0.5% chloramine T solution for one week to ensure disinfection. Following disinfection, we immersed the teeth in a solution consisting of tea. To prepare the solution, we brewed a bag of tea for 5 minutes in a cup of boiling water. The samples were placed in the tea solution for 3 days, and the solution was changed daily. Finally, we polished the teeth using a low-speed handpiece, brush, and Prophy-Mor Micro Black prophylaxis paste (Morvabon, Tehran, Iran). We stored them in normal saline until the study's commencement. The samples were randomly divided into four groups (12 teeth each).

The samples of each group were dried, and each group was fixed separately on a wax sheet (four groups were placed on four wax sheets). In each group, the color of each sample was measured using the CIELab system with a spectrophotometer in three areas: one-third of the incisal, one-third of the middle, and one-third of the gingival surface of the buccal surface. The data were recorded in Excel software.

In the first group, after applying 38% H_2O_2 bleaching gel (LWS, Doctor Smile, Lambda S.p.A, Brendola, Italy) with a thickness of 1.5 mm on the buccal surface of the teeth, Nd:YAG laser (LightWalker II) with a wavelength of 1064 nm, frequency of 25 Hz, power of 2.5 W, and spot size of 320 μm in VLP mode (1000 microseconds), using the R24 handpiece at a distance of 1 mm, was irradiated three times for 20 seconds each, allowing a 20-second interval to prevent temperature rise between applications of irradiation.[23]

In the second group, after placing bleaching gel with a thickness of 1.5 mm on the buccal surface of the teeth, Er:YAG laser (LightWalker II) with a wavelength of 2940 nm, frequency of 10 Hz, power of 0.4 W, and spot size of 5 mm, in VLP mode (1000 microseconds), using the R17 handpiece, at a distance of 1 mm, was irradiated three times for 20 seconds each time with a 20-second interval to prevent temperature rise between each irradiation.[30]

In the third group, after placing bleaching gel with a thickness of 1.5 mm on the buccal surface of the teeth, diode laser (Wiser 3, Doctor Smile, Lambda S.p.A, Brendola, Italy) with a wavelength of 980 nm, power of 2 W, and spot size of 8 mm, at a distance of 1 mm, was irradiated three times for 30 seconds each time with a 30-second interval to prevent temperature rise between each irradiation.[33]

In the fourth group, which was considered a control group, after placing the bleaching gel with a thickness of 1.5 mm on the buccal surface of the teeth, no laser rays were irradiated for activation (Table 1).

The bleaching gel was washed 7 minutes after the bleaching process in the irradiated groups and 20 minutes after the bleaching process in the control group with running water for 30 seconds, and the teeth were dried with an air blower to determine the color.

Table 1. Laser parameters.

Groups	Bleaching gel	Bleaching gel thickness	Laser set	Laser wavelength	Laser frequency	Laser power	Laser spot diameter	Distance working	Bleaching time	Interval time
Nd:YAG	Doctor Smile (38% H_2O_2, Italy)	1.5 mm	LightWalker, Fotona, Slovenia	1064 nm	25 Hz	2.5 W	6 mm	1 mm	3x20 s	20 s
Er:YAG	Doctor Smile (38% H_2O_2, Italy)	1.5 mm	LightWalker, Fotona, Slovenia	2940 nm	10 Hz	0.4 W	5 mm	1 mm	3x20 s	20 s
Diode	Doctor Smile (38% H_2O_2, Italy)	1.5 mm	Wiser, Doctor Smile, Italy	980 nm		2 W	8 mm	1 mm	3x30 s	30 s
Control	DoctorSmile (38% H_2O_2, Italy)	1.5 mm							20 min	

Data collection involved determining the color of the teeth before and immediately after bleaching. For this study, the CIELab system was used to determine tooth color. CIELab is a quantitative index developed by the International Commission on Illumination (CIE) for expressing color. It is a three-dimensional space with three components: L*, a*, and b*. The L* index represents color brightness, ranging from zero (black) to 100 (white). The a* index represents the amount of red-green color, where positive values indicate red and negative values indicate green. The b* index represents the amount of yellow-blue color, where positive values indicate yellow and negative values indicate blue. The color change (ΔE_{ab}*) in this system was calculated using the following formula:

$$\Delta E_{ab}^* = \sqrt{[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]}$$

Statistical analyses

To evaluate the effect of laser type and bleaching technique on color parameters, due to the normality of the data, one-way analysis of variance (ANOVA) was used. The assumption of normality was checked with the Kolmogorov-Smirnov test. SPSS software (version 24) was used for data analysis. An error level of 5% was considered a significant level.

Results

In this *in vitro* study, the examined samples, which included 48 human anterior teeth and premolars, were divided into four groups with Er:YAG, Nd:YAG, and diode lasers and the control group (without laser) after being placed in the bleaching gel. The average color change of the teeth was calculated and analyzed with SPSS software version 24.

Comparison of average color change (ΔE) by ANOVA test showed a significant difference between the average ΔE in all experimental groups ($p<0.05$). According to the results of Tukey's multiple comparisons test, the average ΔE in the diode laser group was significantly higher than the Nd:YAG and Er:YAG laser groups ($p<0.05$), while the Nd:YAG and Er:YAG had no significant difference in mean ΔE with each other ($p>0.05$). Also, the average ΔE in the control group (without laser radiation) was significantly lower than the diode laser group ($p<0.05$) and higher than the Nd:YAG and Er:YAG laser groups ($p<0.05$).

The findings from the independent t-test, which aimed to compare the average color change in the groups subjected to laser irradiation with that of the control group without laser treatment, indicate that there is no statistically significant difference. Specifically, the average color change of teeth treated with 38% hydrogen peroxide using Nd:YAG, Er:YAG, and diode lasers does not differ significantly from the average color change observed in the control group treated with 38% hydrogen peroxide without laser application ($p>0.05$) (Table 2, Figure 1).

Discussion

This study compared the amount of tooth color change post-bleaching with Nd:YAG, Er:YAG, and diode lasers. Usually, ΔE is used to evaluate bleaching quality in studies.[16] Studies have shown that ΔE greater than 3.3 is a clinically acceptable color change threshold. ΔE between 3.3 and 8 is a medium value, and ΔE above 8 is a significant value for the human eye.[34,35] Based on this, the results showed a diagnostic color change in all groups of our study.

Colorimetry can be done with different methods. In this

Table 2. Comparison of average color parameters ΔL, Δa, Δb, and ΔE in Nd:YAG, Er:YAG, and diode lasers and control groups.

	ΔE	Δb	Δa	ΔL
Nd:YAG	5.48±0.72 (4.43-6.74)	-4.1±0.47	-0.53±0.56	3.6±0.61
Er:YAG	5.14±0.59 (4.24-6)	-3.8±0.54	-0.43±0.41	3.45±0.32
Diode	10.16±0.95 (8.6-11.88)	-6.72±0.85	-2.8±0.78	7.1±1.21
Control	7.22±0.81 (6.03-8.49)	-5.32±0.57	-1.1±0.69	4.77±0.84
P-value	0.05>	0.05>	0.05<	0.05>

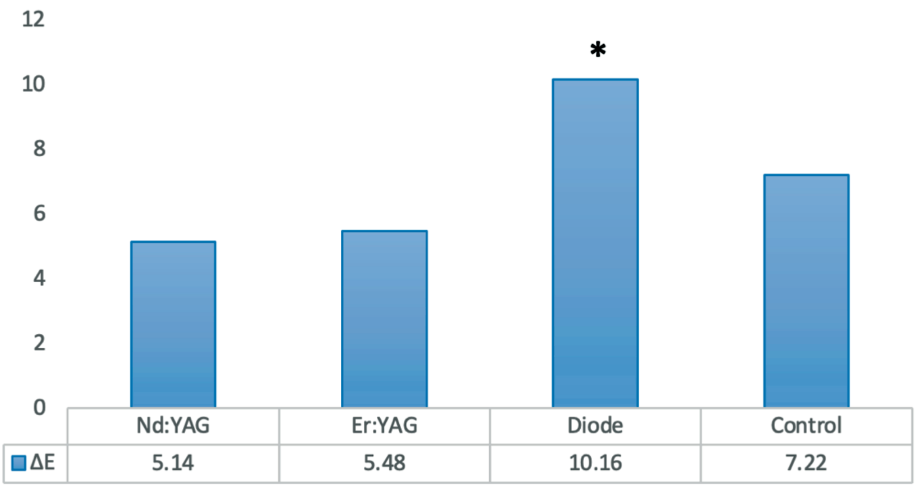

Figure 1. Comparison of average color parameter E in Nd:YAG, Er:YAG, and diode lasers and control groups. *P-value<0.05.

study, the spectrophotometric method was used, which has high accuracy and is usually used for this purpose.[36] CIELab color parameters were measured in this study. Based on the spectrophotometric findings, the increase in whitening happens with the increase in brightness (parameter L), decrease in redness (parameter a), and decrease in yellowness (parameter b).[37] In all groups, parameter a did not change significantly after bleaching, while the L parameter increased and the b parameter decreased significantly. In other words, the teeth became brighter after bleaching, and the degree of yellowness decreased.

The findings showed a significant difference between the average ΔE in all studied groups. The average ΔE in the diode laser group was significantly higher than that of the Nd:YAG and Er:YAG laser groups, which showed no significant difference in their average ΔE. This difference may arise because the laser and its parameters need to align with the bleaching gel and the intended effect.[36,38] The lower effect of Nd:YAG laser on the degree of teeth color change can be attributed to the use of a fiberoptic system and hand movement during the bleaching process. Additionally, similar to the Er:YAG laser, this laser exhibits lower absorption in our pink bleaching gel due to reduced pigment interaction. For this reason, both lasers are generally less effective than the diode laser, which is absorbed into the pigmented bleaching gel more quickly and thoroughly.

Activating a bleaching agent can speed up the teeth whitening, although the result may have the same or a different effect than conventional bleaching (without light activation sources).[39] In this study, the average ΔE in the control group (without laser radiation) was significantly lower than that in the diode laser group. However, in the study by Kiomarsi *et al.*,[20] the amount of color change in the control group exceeded that of the laser radiation groups. This difference may result from the method used in the bleaching process. In the control group of this study, the bleaching gel was applied to the teeth three times for 20 minutes each, whereas in our study, the bleaching gel was administered only once for 20 minutes.

In our study, the average ΔE in the control group was significantly higher than in the Nd:YAG and Er:YAG laser groups. This could be because the gel was in contact with the teeth for a longer time in the control group compared to the other two groups. As a result, it increased the effect of the control group on the degree of teeth color change compared to these two groups that were in contact with the bleaching gel for a shorter period of time, and did not have the necessary efficiency due to the parameters in the laser and bleaching gel.

One of the most critical factors affecting bleaching is the H_2O_2 concentration in the bleaching gel.[20] To more accurately examine the effect of lasers in tooth bleaching, we used the same bleaching gel containing 38% hydrogen peroxide in all groups of this study. While in other studies, including the study of Möbius *et al.*,[40] and the study of Saluja *et al.*,[41] different concentrations of H_2O_2 were used in each group, which can be due to the

different methods of gel activation in each group so that a better accordance can be made between the parameters of the activation sources and the gel used.
In this study, the inability to follow up on long-term teeth color changes does not allow for evaluating the stability of the bleaching treatment's color change. Also, due to the novelty of laser bleaching methods, there is not enough information about the effectiveness of different bleaching agents. Therefore, future studies with longer follow-ups are needed to evaluate the long-term outcome of different bleaching methods specific to laser application. In addition, clinical studies are needed to confirm *in vitro* findings.
Given that no comparative study has been conducted on the methods examined in this study, it is challenging to evaluate these results and draw conclusions from them. Further research is necessary to explore the effects of different wavelengths of diode lasers on tooth color change. The thermal effect of the diode laser with varying parameters on pulp tissue should be considered to ensure the safety of the bleaching process in clinical conditions. Long-term clinical studies will possibly reinforce the findings of this study.

Conclusions

There was a significant difference in the degree of color change of teeth among the various laser groups. The diode laser resulted in the greatest amount of color change, while the Er:YAG laser resulted in the least amount of color change across all groups. Despite the limitations of this study, it was concluded that the diode laser operating at a wavelength of 980 nm yields more pronounced whitening effects in laser-assisted bleaching compared to other wavelengths, specifically Er:YAG and Nd:YAG lasers.

Contributions

MS, NC, conceptualization; NC, methodology; NI, LS, formal analysis; NC, NI, investigation; NI, writing – original draft preparation; NI, NC, writing – review and editing; SB, sources; MS, NI, NC, supervision. All the authors have read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of interest

The authors have no conflict of interest to declare.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Alborz University of Medical Sciences (IR.ABZUMS.REC.1402.251).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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