Systematic Review

Effectiveness of KTP lasers in tooth bleaching, by comparing tooth color change after bleaching with KTP, Nd:YAG, Er:YAG, and diode laser system: A systematic review

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Abstract

This systematic review evaluated the role of Potassium-titanyl-phosphate (KTP) lasers in dental bleaching by comparing tooth color change and rise in intrapulpal temperature after bleaching with KTP, Neodymium-doped yttrium aluminum garnet (Nd:YAG), Er:YAG, and diode laser system. Following were the inclusion criteria: in vitro studies in English available in full text. Articles published between 2000 and 2021 were selected. The search for was conducted on PubMed, Cochrane library/CENTRAL, Wiley online library, ProQuest, Science Direct, and Hand searching/specialized registers. Keywords were used: "Lasers" [Mesh] and "Tooth bleaching" [Mesh] using Boolean operators. A total of four articles fulfilled the inclusion criteria. The quality assessment of studies included was undertaken independently as part of data extraction process. KTP lasers demonstrated more effectiveness in attaining color change in stained teeth and showed the lowest rise in intrapulpal temperature. Based on the data obtained in the present review, the choice of bleaching treatment is directly related to the type of discoloration, activation of the bleaching agent, and esthetic requirement. Although all bleaching procedures were effective in color change, the KTP laser showed better results when compared to other laser activation. The bleaching treatment protocol is directly related to the type of discoloration, activation of the bleaching agent, and esthetic requirement. It has been demonstrated that a faster change in color can be obtained when bleaching is performed in combination with a light source, i.e., power bleaching aiming for a more in-depth change of color.

Keywords: Colorimeter; hydrogen-peroxide; lasers; spectrophotometer; tooth-bleaching

INTRODUCTION

Esthetic dentistry has become an important part of dental practice over the past decades. In dental esthetics, we strive toward mimicking and customizing a treatment plan which will harmonize with nature. This ensures that the reestablished new smile not only highlights the esthetic features but also adapts to the patient's lifestyle, job, and social position.[1]

The most important factor in patients' perception of dental attractiveness is the tooth shade which results from the science involved in diffused reflectance of light from the dentin through the translucent enamel layer. According to Randa *et al*., one-third of the population is not happy with the color and the form of their natural teeth.[2,3]

Discoloration of teeth is the most common reason for which patients seek treatment. Tooth discoloration occurs due to various causes, which can be intrinsic or extrinsic in nature. Extrinsic discoloration arises due to the deposition of external chromogens on the tooth surfaces or in the pellicle. Intrinsic discoloration occurs when the

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chromogens are deposited in the tooth structure usually in dentin and are systemic or pulpal in origin. A plethora of treatment options of varying invasiveness have been proposed to manage discolored teeth, which includes external bleaching, microabrasion, dental veneers, crowns, or a combination of methods.[2] The American Academy of Cosmetic Dentistry reported that 90% of patients opt for bleaching as a treatment choice[4] which is considered to be the most minimally invasive one.[5]

In vitro studies on Potassium-titanyl-phosphate (KTP) lasers are scarce. One of the most challenging cases for bleaching to produce satisfactory results is tetracycline-stained teeth. When tetracycline is taken during the teeth's formative years, the dentin develops a distinctive blue-gray or yellow-brown opalescent coloring. The tetracycline stains appearance may be continuous or laid down in stripes depending on whether the ingestion was uninterrupted or halted.[6] As both tetracycline-calcium chelate compounds and bleaching gel absorb visible green light in the 525–540 nm range, one can consider that both light sources (Light emitting diode (LED) and KTP laser) could be of value.[7]

KTP laser bleaching as compared to the other light-activated bleaching systems, focuses more on breaking the tetracycline molecules to eliminate greyish colorations. Photodynamic bleaching with KTP laser produces no significant adverse effects on the oral soft tissues, dental pulp, or tooth structure.[8] Energy transfer of KTP laser has demonstrated controlled heating of the gel and not the tooth causing minimum damage to the dentine pulp complex. Furthermore, because of its specific wavelength, it may photooxidize the chelates formed between tetracyclines and hydroxyapatite or calcium orthophosphate.[9] The benefits of an in-office whitening operation over a home bleaching technique are clear despite the fact that home bleaching is efficient and has gained widespread acceptance during the past 10 years. It is also possible to use in-office bleaching as a form of boost therapy to start the bleaching process, which may then be maintained at home. This implies that for best results, the dentist-assisted bleaching treatment must be repeated over the course of several visits.

High concentrations of bleaching agents such as $H2O_2$ (30%–35%) are used during in-office-bleaching. Although there is enormous advancement in the procedures and materials incorporated for the bleaching techniques, the lengthy procedural time and supplemental appointments required are still a daunting problem. To cut through the same, activation of the bleaching agents to allow for a quicker treatment was postulated.[9,10]

Comprehensive research in view of this has thrown light on the use of different types of sources for activation of the bleaching agent such as halogen curing lights, plasma arc lamp, xenon–halogen light, and lasers.[10]

Different types of lasers have been time tested for the activation of the bleaching gel, like diode, Erbium-yttrium-aluminum-garnet (Er:YAG), Nd:YAG, and KTP lasers of which the KTP lasers have emerged to give promising results. Laser-assisted bleaching uses laser beam to accelerate release of free radicals within the bleaching gel to decrease time of whitening procedure.[11] KTP laser device, invented for in-office bleaching, has unique optical and chemical interactions which make photochemical bleaching possible by promoting oxidation in a controlled manner.[12] This makes single dental visits more effective as compared to several months of wearing bleaching trays.[7]

Photodynamic bleaching using the KTP laser is useful in treating staining due to dental sclerosis from the aging process, without any adverse effects on the oral soft tissues, dental pulp, or tooth structure.[7] It has been demonstrated that the KTP laser in association with hydrogen peroxide gel is currently the only system providing laser bleaching with photothermal, photochemical, and photocatalytic activation of the bleaching gel.[7] Conventional bleaching has demonstrated a rise in temperature by approximately 1.5° centigrade.[13] Use of lasers for activation of bleaching is also accompanied by rise in temperature in the range of 2°C–8°C for LED, diode, and KTP lasers.[14] Temperature fluctuation below the critical temperature of 5.5° can be detrimental to the pulp.[15] However, it is necessary to compare their effects in an evidence-based manner. Thus, this systematic review was conducted with an aim of comparing the color change of tooth when HP was activated with KTP, Diode, Er:YAG, and Nd:YAG lasers.

Focus question

Does the use of KTP laser produce a better tooth color change in a discolored tooth compared with other lasers.

Objectives

The objective of the study was to determine the color change after laser activation and temperature rise.

METHODOLOGY

Protocol and registration

This review has been registered in PROSPERO; International Prospective Register of Systematic Reviews funded by the National Institute of Health Research and produced by Centre for Reviews and Dissemination an Academic Department of the University of York. It is an international database for registration of systematic review containing detailed protocol of the review that can be accessed by all and helps to avoid duplication of the review. The registration number of this review is CRD42022298510 and can be accessed on the website.

https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42022298510.

Eligibility criteria

Inclusion and exclusion criteria were.

Inclusion criteria

1. Studies that have compared KTP lasers with other lasers in tooth bleaching
2. Study design: *In vitro* studies
3. Studies on discolored permanent teeth
4. Studies conducted on human teeth
5. Studies showing outcomes published in English language only
6. Studies published from 2000 till 2021
7. Studies in which the outcomes are chroma, value, hue, color change, and temperature change.

Exclusion criteria

1. Studies on teeth presenting with pulpitis and vital pulp therapy
2. Studies showing teeth with previous treatment to necrosis
3. Studies including teeth with developmental anomalies (e.g., dens invaginatus), transplanted teeth as well as avulsed and re-implanted teeth will be excluded
4. Teeth with cracks or fracture line
5. Carious teeth
6. Root canal-treated teeth
7. Already restored teeth
8. Studies published in other languages.

Information sources

Keywords related to Bleaching AND Lasers/KTP lasers AND Bleaching/Bleaching AND ND: YAG/Bleaching AND Er: YAG/Bleaching AND Diode lasers/Bleaching AND CO_2 were used for the literature search.

Data were searched through the databases, PubMed, ProQuest, and Cochrane from January 1, 2000 to May 31, 2020. Cross-references were checked for relevant articles, and relevant studies which were not available through electronic database were hand searched for full texts.

Search

The comprehensive data search was performed in PubMed, Cochrane Library, and ProQuest. While carrying out the search through PubMed, the filters were put for the dates of publication as January 1, 2000–May 31, 2021. We included studies published in the English language. Studies were excluded through language only if the data could not be translated in English. No filters for study design or full-text articles were set. The keywords for the search were decided by reviewing the literature. The search strategy used in PubMed for searching articles was Bleaching AND Lasers.

KTP lasers AND Bleaching/Bleaching AND Nd: YAG/Bleaching AND Er: YAG/Bleaching AND Diode lasers/Bleaching AND CO_2.

Example-Bleaching AND Lasers, KTP lasers AND Bleaching, Bleaching AND Nd: YAG, Bleaching AND Er: YAG, Bleaching AND Diode lasers, Bleaching AND CO_2.

Four search strategies were formed with the effectiveness of KTP lasers in tooth bleaching.

PubMed and ProQuest search yielded 1606 titles and a search of Cochrane database yielded 156 articles.

Study selection

In the first stage, two review authors independently screened the titles. Titles that met the inclusion criteria were included for screening of the abstract. In the second stage, abstracts obtained by search strategy were screened and included for full-text screening if they met the inclusion criteria. In the third stage, full texts of all the included abstracts were obtained and subjected to review. Articles that met the inclusion criteria were retained, and the rest were excluded from the review. All the excluded studies were recorded with reason for exclusion for each study. None of the authors were blinded to the journal titles, study authors, or the institutions where the studies were conducted.

Data collection process

The following criteria were predetermined for extracting the data:

1. Color change and temperature change after activation with KTP laser [Table 1]
2. Other outcomes of different laser activation for the management of discolored teeth [Table 2].

The data extraction includes journal name, year, study type, objectives, methodology, sample size, pre-bleaching, stabilization of extracted teeth, description of activation

Table 1: Search strategies used, the articles that got searched and selected

Search strategies	Articles in search	Articles selected
Bleaching AND lasers	1222	789
KTP lasers AND bleaching	83	49
Bleaching AND Nd:YAG lasers	95	50
Bleaching AND Er:YAG lasers	85	32
Bleaching AND diode lasers	102	45
Bleaching AND CO_2 lasers	19	5
Total	1606	970

Table 2: Data extraction

	Author			
	Zhang *et al*.[12]	Nguyen *et al*.[19]	Yang Gao *et al*.[18]	Shahabi *et al*.[8]
Journal	*Photomedicine and Laser Surgery*	*Lasers Med Sci*	*Photodiagnosis and Photodynamic Therapy*	*Journal of Lasers in medical sciences*
Year	2007	2015	2020	2018
Geographic location	Tokyo, Japan	France	China	Iran
Study design	*In vitro*	*In vitro*	*In vitro*	*In vitro*
Objectives	Evaluate the effects of a KTP laser, a diode laser, and a LED	Two different concentrations of HP (6% + and 35%) alone and with KTP (532 nm) and Er:YAG (2940 nm) irradiation	The aim of this study was to compare the results of thermal elevation and bleaching efficacy alone and with laser irradiation, to investigate the relation among laser source, bleaching gel, and color change	The aim of this study was to evaluate tooth color changes, following conventional and light-activated in-office bleaching techniques, by different light sources, using a spectrophotoradiometer
Methodology	35% HP + KTP 35% HP + diode 35% HP + LED	35% HP 35% HP + KTP 35% HP + Er:YAG	35% HP 38% HP 35% HP + KTP 38% HP + KTP 35% HP + Nd:YAG 38% HP + Nd:YAG	40% HP + LED 40% HP + KTP 40% HP + diode 40% HP + Nd:YAG 40% HP + CO_2
Sample size	40 human extracted maxillary incisors	36 healthy human central and lateral incisors, canines, and premolars	30 human maxillary permanent central incisors and 30 premolars	70 sound anterior teeth
Prebleaching preparation of sample	Apical foramen → sealed with wax; exposed dentin and cementum- coated by two layers of nail varnish	Teeth → ultrasonic scaling, cleaned with prophy paste; the roots were separated	Teeth stored in 0.2% thymol to inhibit microbial growth → immersed for 72 h in an Orange II solution	Teeth → cleansed by prophypaste All samples immersed in chloramine T for 1 week and stored in distilled water
Stabilization of extracted teeth	Positioning appliance fabricated for each tooth with ethylene vinyl acetate → hold the test surface and angle the tooth to the measuring head of the colorimeter	A silicone key was prepared for each sample for easily repositioning the tooth in front of the digital shade-matching system	Teeth were stabilized in an acrylic plastic base with an autopolymerizing resin	Teeth were mounted in a self-cure transparent acrylic resin with a background of TiO_2
Description of activation devices used	KTP laser - 532 nm, 1.0 W (SMARTLITE D) Diode laser - 980 nm, 1.0 W; Elipar Freelight (3M, St. Paul, MN) with an LED of blue color light - 470 nm	A KTP laser - 532 nm, 1W (continuous mode, 2 cm working distance, 8 mm spot size diameter) Er: YAG laser 2940 nm, 50 mJ pulse energy, VLP mode (pulse duration 1000 μs), 10 Hz frequency, 2 cm working distance and 5 mm spot size diameter	KTP laser - 532 nm Nd:YAG laser - 1064 nm	LED activation at - distance of 5–6 mm between the bleaching handpiece and the sample KTP laser (λ=532 nm) 4 mJ, pulse width=20 ns, power=4/20=0.2×106 W, repetition rate=10 Hz, beam diameter=1.5 mm Diode laser (810 nm) Nd:YAG laser (λ=1064 nm) (Fotona, Slovenia, EU) with repetition rate=20 Hz, pulse width=20 ns, energy=100 mJ, beam diameter=3 mm, pulse power=E/ζ=(100 mJ/20 ns)=50 mW CO_2 laser (λ=10,600 nm), using the following parameters: Power=0.6 W, repetition rate=20 Hz, level 3 (current pulse length=1.5 ms)
Bleaching gel	35% HP (Hi- Lite, Shofu, Kyoto, Japan)	35% and 6% HP (PolaOffice, Australia)	35% HP (Beyond, Beyond Tech Corp, USA); 38% HP (Opalescence Boost, Ultradent, USA)	40% HP (Opalescence, USA)
Temperature measurement	A thin K-type thermocouple (diameter 0.5 mm) During exposure, temperature changes in the pulp chamber were measured by a thermometer	Thermocouple was used to measure the temperature	The root canals were filled with a thermally-conductive paste. A K-type thermocouple probe with a digital thermometer was used to measure the temperature	Not mentioned
Devices used to measure the color change	A colorimeter (Minolta CR-410; Konica Minolta Co., Tokyo, Japan)	The ShadePilot is a digital camera linked to a LED spectrophotometer	The color distributions were measured by the CIE-lab system using a dental colorimeter (Crystaleye, Olympus, Japan)	Spectrophotoradiometer was used to evaluate tooth color changes following different office bleaching techniques

Contd...

Table 2: Contd...

	Author			
	Zhang *et al*.[12]	Nguyen *et al*.[19]	Yang Gao *et al*.[18]	Shahabi *et al*.[8]
Statistical analysis	Kruskal–Wallis test	Kruskal–Wallis test and Mann–Whitney test	One-way ANOVA test and *t*-test	Two-way ANOVA as well as *post hoc* ANOVA test
Results	Mean total color difference value (△E*) >5.0 was obtained in each group. KTP laser-induced bleaching (Group 1) gave a significantly higher L* after treatment	The ΔE values between the group with gel without laser irradiation and the group with gel+KTP irradiation did not show significant differences value=0.1489>0.05	KTP + OB (35% HP) group showed the largest ΔE* value among all groups ($P<0.05$), but decreased significantly 15 days after the end of bleaching	Not mentioned clearly
Mean value (color change) △	KTP - △E=8.79 (3.05) Diode - △E=5.74 (2.04) LED - △E=6.41 (2.47) 35%HP - △E=5. 22 (2.20)	35% HP+KTP - △E=2.88±1.45 35% HP+Er:YAG - △E=3.7±1.81 35% HP - △E=2.15±1.3	Graphically represented	Not mentioned
Mean value (temperature change) °C	KTP - 3.76 Diode - 7.72 LED - 2.95	Graphically represented	KTP - 3.71±0.58 Nd:YAG - 2.40±0.62 35% HP - 0.12±0.02	Not mentioned

*delta E. ANOVA: Analysis of variance, Er: YAG: Erbium: yttrium aluminum garnet, pulsed, Nd: YAG: Neodymium: yttrium aluminum garnet, pulsed, KTP: Potassium-titanyl-phosphate, HP: Hydrogen peroxide, LED: Light-emitting diode, OB: Opalescence Boost, CIE: Commission Internationale de l'Eclairage

devices, bleaching gel, temperature measurement, devices used, statistical analyses, results, mean color change, and mean temperature change values.

Risk of bias in individual studies

Risk of bias in all included studies was assessed using the criteria adapted from checklist for reporting *in vitro* studies (CRIS) and Newcastle-Ottawa Quality Assessment Scale which was customized for this systematic review [Table 3]. The concept and standardization of criteria included in the risk of bias was adapted from CRIS guidelines and to access the quality of the studies star system was adapted from Newcastle–Ottawa Quality Assessment Scale.[16,17] A score of one was given for fulfilling conditions in each domain and zero when unclear or otherwise. The maximum possible score was 15 and a study scoring 13–15 was classified as high-quality study, 9–12 as moderate quality study, and less than or equal to 8 as low-quality study [Table 4]. The judgment for assessing the quality of the study was made independently by two review authors based on the criteria mentioned below [Table 4]. It was later crosschecked by the other review author. Any disagreements if present were resolved by discussion.

RESULTS

Study selection

One thousand and six hundred and six records were identified through data search using search strategy in PubMed, ProQuest, and Cochrane. The second step was screening through titles. After screening through titles, 1189 articles were excluded because the titles did not meet the inclusion criteria. Four hundred seventeen articles were screened for duplicates through Endnote Software VersionX7, and 389 duplicates were removed. Abstracts were screened for the remaining 28 articles. Seventeen articles were excluded after the review of abstracts because they did not meet the inclusion criteria [Table 1]. In the third stage, full texts were obtained for the remaining 11 articles and a full-text review was performed. After performing a full-text review, four articles which met the inclusion criteria were included for qualitative analysis. Seven were excluded because two articles were published in different languages, three articles included other lasers, and two articles used bovine teeth.

Study characteristics

Four articles were included in the systematic review [Figure 1]. Of the four investigations that were mentioned, two used diode lasers (ZHANG, *et al*. 2007 and Shahabi *et al*. 2018),[8,12] two used Nd: YAG (Yang Gaoa *et al*. 2020 and Shahabi *et al*. 2018),[8,18] and one used Er: YAG (Nguyen *et al*. 2015).[19] The maximum concentration of hydrogen peroxide employed in all trials was in the range of 30%–40%.

Risk of bias in individual studies

Table 1 shows the impact of treatment for all outcomes reported in the *in vitro* investigations. Compared to conventional bleaching therapy laser activation of the bleaching agent improved all the colorimetric aspects according to the Commission Internationale de l'Eclairage to a clinically and statistically significant extent. The quality of each study was assessed using the risk of bias tool customized for this study. Furthermore, apart from bleaching mean intrapulpal temperature change, microhardness test and morphological analysis were evaluated. The risk of bias in the studies included in this review is summarized in Tables 3 and 5. Three studies had low risk of bias, one study is categorized as medium risk of bias.

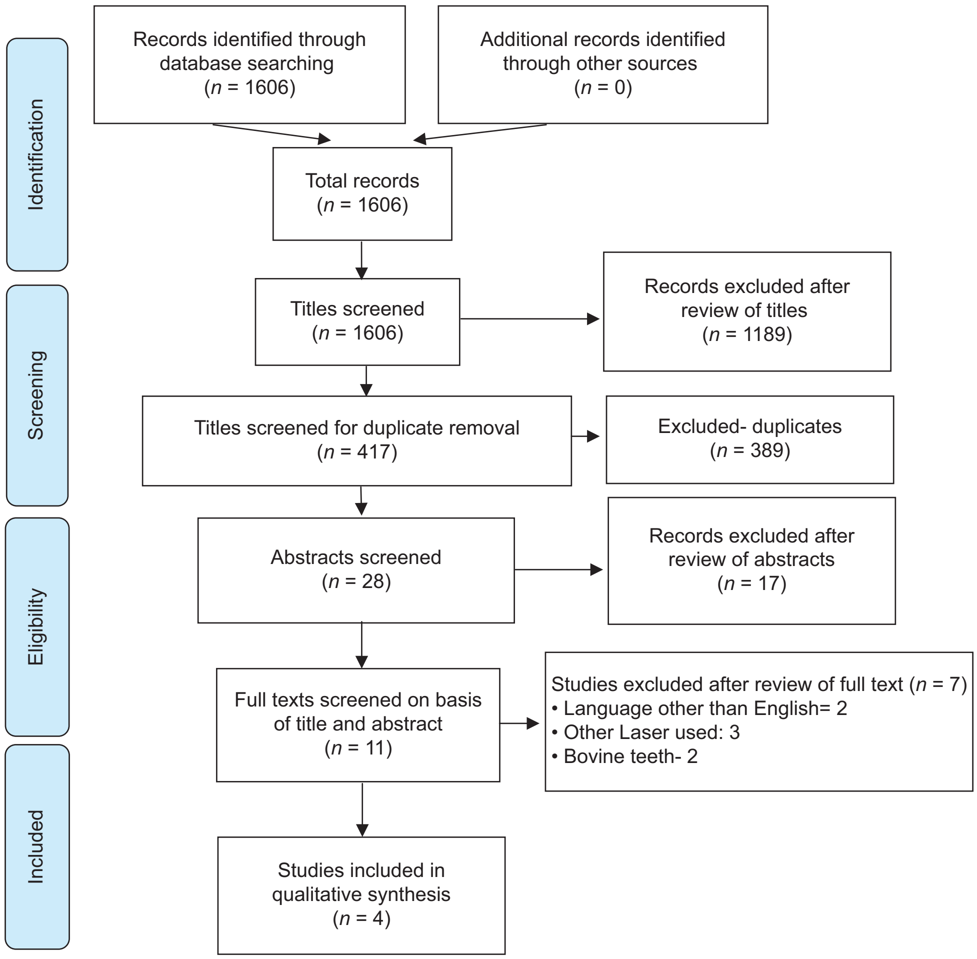

Figure 1: Flow diagram depicting the process of selection and exclusion of articles at each step

Table 3: Risk of Bias Assessment Tool

	Criteria	Chengfei Zhang[12]	C. Nguyen[19]	Yang Gao[18]	Shahabi[8]
1	Quality of extracted teeth	*	-	*	-
2	Prebleaching preparation of sample	*	*	*	*
3	Stabilization of extracted teeth	*	*	*	*
4	Sample size	*	*	*	*
5	Description of activation devices used	**	**	**	**
6	Bleaching gel preparation	*	*	*	*
7	Concentration of H_2O_2-30–40	*	*	*	*
8	Temperature measurement	*	*	*	-
9	Device used to measure the color change	*	*	*	*
10	Statistical analysis	*	*	*	*
11	Results: Mean value (color change)	**	**	*	-
12	Results: Mean value (temperature)	**	*	**	-
	Total	15	13	14	9

Score of *was given to represent Low risk, Score of **was given to represent Unclear risk, No Score was given to represent High risk

Risk of bias across studies and additional analyses

Several supplementary studies, including sensitivity analyses for meta-analysis, were planned during the protocol stage but could not be carried out due to heterogeneity.

Results of individual studies

In the present review, the search narrowed down to a set of 4 *in vitro* experiments which were carried out on extracted teeth samples or similar conditions mimicking the oral environment.

Characteristics of interventions

Of the four studies reported two used diode lasers,[7,11] two used Nd: YAG,[7,17] and one used Er: YAG.[18] All the experiments used hydrogen peroxide from the range of 30%–40% as the highest concentration.

Table 4: Description of low risk, unclear, and high risk

Serial number	Criteria	Low risk/unclear/high risk	Stars awarded
1	Quality of teeth	Low risk - study should extracted teeth free of caries, restorations, or any deformities High risk – when there is no mention of the quality of the extracted teeth	* -
2	Prebleaching preparation of sample	Low risk - articles should mention the prebleaching procedure like cleaning the tooth of all debris, calculus, use of polishing paste, and storage in thymol till use High risk - no description mentioned- no prebleaching prepration done	* -
3	Stabilization of extracted teeth	Low risk - articles should mention the method of stabilizing the teeth while measuring the color change such as the use of autopolymerizing resin, a silion key or ethylene vinyl acetate High risk - no stabilization method used	* -
4	Sample size	Low risk - mention of sample size and sample distribution among the groups High risk - if article has no mention of the sample size or its distribution	* -
5	Description of activation devices used	Low risk - articles should mention the activation device used along with its wavelength, power, and mode (type of lasers, LED) Unclear - incomplete information of the activation device used along with its wavelength, power and mode (type of lasers, LED) High risk - if articles have not mentioned any description of the activation device used	** * -
6	Bleaching gel	Low risk - the concentration/method of preparation of bleaching gel (HP) used should be mentioned (30%–40%) High risk - if the article has not mentioned about the name of the bleaching gel or its concentration	* -
7	Temperature measurement	Low risk - the device used for measuring temperature should be mentioned (thermocouple/ thermometers) High risk: The device used for measuring temperature is not mentioned (thermocouple/thermometer)	* -
8	Shade measurement	Low risk - the device used for measuring color should be mentioned (use of colorimeter, spectrophotometer as they provide superior results) Unclear - inadequate information High risk - if the device used for measuring colour is not mentioned (colorimeter, Spectrophotometer)	** * -
9	Statistical analysis	Low risk - the tests for statistical analysis should be clearly mentioned High risk - the tests for statistical analysis are not clearly mentioned	* -
10a	Results Mean value (color change) △E	Low risk - the mean value for color change △E should be mentioned separately for all the activation devices used Unclear - inadequate information or is graphically represented from which the mean value cannot be obtained High risk - the mean value for color change △E is not mentioned separately for all the activation devices used	** * -
10b	Results Mean value (temperature)	Low risk - the mean value for temperature change △T should be mentioned separately for all the activation devices used Unclear - inadequate information or is graphically represented from which the mean value cannot be obtained High risk - the mean value for temperature change △T is not mentioned separately for all the activation devices used or is graphically represented	** * -

Score of *was given to represent Low risk, Score of **was given to represent Unclear risk, No Score was given to represent High risk. The study can be awarded a maximum of 15 stars, 13d entedfor all the activation devices usedom w-quality study, 9ars, 13d entedfor all the activation devices usedom which the mean value cannotLight-emitting diode

Table 5: Overall risk

Study	Risk
Chengfei Zhang *et al*.[12]	Low risk
C. Nguyen *et al*.[19]	Low risk
Yang Gaoa *et al*.[18]	Low risk
Shahabi *et al*.[8]	Moderate risk

For description of the intervention refer Table 2.

Color change

Among the four studies, two studies compared the efficacy of KTP laser and diode laser in tooth bleaching. Zhang *et al*. compared color change after activation of bleaching agent (hydrogen peroxide 35%) by KTP laser (ΔE = 8.79 [3.05]) and DIODE laser (ΔE = 5.74 [2.04]). The mean total color difference value in KTP-induced bleaching was significantly higher after treatment. DIODE laser and Light emitting diode (LED) failed to show any significant color changes. KTP laser was able to improve the bleaching result compared with DIODE laser. The study by Shahabi *et al*. compared the tooth color change after bleaching with KTP, DIODE, and Nd: YAG lasers. This study gave the best tooth whitening results with KTP laser.[7,11]

Two studies compared color change with KTP and Nd:YAG laser, the mean color change value was significantly higher in the KTP group when compared to Nd:YAG in both studies (values are graphically represented).[7,17]

One study compared the color change with KTP and Er:YAG laser (C. Nguyen *et al*. 2015),[18] this study showed that Er:YAG laser (ΔE = 3.7 ± 1.81) had the best performance and KTP showed insignificant results when compared to the control group (ΔE = 2.88 ± 1.45).[14]

All the studies used a colorimeter, spectrophotometer, and spectrophotoradiometer for recording the color change, and calculation was done using CIE L*a*b*. Color evaluation is made easier, and results are more accurate and objective when using instrumental methods such as spectrophotometers and digital cameras.[20]

Intrapulpal temperature

It should be noted that all bleaching activation modes mentioned may be accompanied by a temperature increase at the tooth surface, but also in the pulpal chamber.[21] Among the four studies, three have mentioned mean intrapulpal temperature change. The device used to record the rise in intrapulpal temperature is a thermocouple probe. Zhang *et al*. reported the highest temperature rise with the diode laser (7.72°C), Nguyen *et al*. reported the highest temperature rise with Er: YAG laser (graphically represented) and Gao *et al*. reported the highest temperature rise with KTP laser (3.71 ± 0.58°C). The lowest temperature rise was noted with KTP laser by two of these studies which was contrary to the results in the study conducted by Gao *et al*. [Table 2].[11,17,18]

Other outcomes

Microhardness

Apart from color change and rise of intrapulpal temperature other outcomes were studied by the authors. They include the microhardness test by Chengfei Zhang *et al.* (2007)[12] (graphically represented) who reported that there was no significant difference seen in Vickers hardness values of the groups.

Morphological changes

The morphological analysis was evaluated by standard error of mean observations by Nguyen *et al*. who concluded that slight morphological changes were observed on the enamel surface after treatment with all procedures.[11,18]

DISCUSSION

To our knowledge, this is the first systematic review to report the efficacy of KTP laser in tooth bleaching by comparing tooth color change after activation with KTP, Nd:YAG, Er:YAG, and diode lasers. The results of the search revealed that till date, no clinical trials among human subjects have been reported which tested color change after activation of bleaching agent with KTP lasers. All lasers work by delivering energy in the form of light. The use of lasers is definitely minimally invasive and less painful. The disadvantages include high cost and increase in intrapulpal temperature.[22]

With the data available till now, among all types of lasers, KTP (potassium-titanyl-phosphate) laser has proven to be a new gold standard. The KTP laser releases green visible radiation which is poorly absorbed by water and hydroxyapatite but selectively by hemoglobin and melanin. It has the ability to break tetracycline molecules and eliminate the grayish colorations. As evaluated in these studies, KTP laser surely causes lower thermal effects and is able to improve the bleaching performance.[14]

In tooth whitening using hydrogen peroxide gel, a laser is utilized to release free radicals, which in turn breaks down dark pigmented molecules present on teeth, facilitating their removal.[22]

This review summarizes evidence from 4 *in vitro* studies on the efficacy of KTP lasers versus, DIODE laser, Er: YAG laser, and Nd: YAG other lasers in bleaching. According to evidence, bleaching with HP and laser activation is effective in significantly improving the colorimetric properties of the discolored teeth. The KTP laser tends to penetrate dentin more readily because its wavelength is not well absorbed by water (because dentin has abundant water), and the gel penetrates through the outer enamel and into the dentin layer, giving the tooth surface a lighter reflection, resulting in whiter teeth [Table 6].[23]

Studies of color change on bovine teeth after bleaching with 30% hydrogen peroxide activated using KTP and diode laser have demonstrated better results with KTP lasers.[17,23] Titration of hydrogen peroxide was assessed by Fornaini *et al.* (2013) who observed that high HP concentrations do not improve the efficacy of the bleaching process and are detrimental to the tooth. Studies using bovine teeth were excluded from our review because they are generally brighter than human teeth and they show less variability in shade.[18,24]

Table 6: Overview of laser activation sources

Laser	Wavelength (nm)	Color emitted and output power	Properties
KTP laser	532	Green	Relatively low absorption in water and tooth mineral; high absorption in hemoglobin; medium penetration depth into dental hard tissue
Diode laser	810, 830, 970, 980	Infrared	Low absorption in water and tooth mineral; absorption in pigments; deep penetration into dental hard tissue – pulp damage due to temperature rise
Nd:YAG laser	1064	Infrared	Low absorption in water and tooth mineral; absorption in dark pigments; deep penetration into dental hard tissue – pulp damage due to temperature rise
Er:YAG laser	2790	Short wave infrared	Highest absorption in water and high absorption in tooth mineral (OH−); low penetration depth into dental hard tissue – relatively low risk of direct pulp damage

Er:YAG: Erbium: yttrium aluminum garnet, pulsed, Nd: YAG: Neodymium: yttrium aluminum garnet, pulsed, KTP: Potassium-titanyl-phosphate

External heat applied to the teeth can cause pulp damage in varying degrees, depending on the magnitude and duration of the increase in temperature . In an in vivo study an increase in temperature inside of the pulp chamber of 5.5°C caused irreversible pulpits.[25]

The results of this review cannot be extrapolated to that of any clinical outcomes because factors, including daylight, ambient light, ambient conditions, and patient-related factors (such as age, gender, the color of the patient's natural teeth, the patient's sitting position, and the use of makeup) can affect the color.

In this present systematic review, three studies were categorized as high-quality studies, one study is categorized as moderate quality [Table 5].

During the literature search of our systematic review, we encountered a few lacunae, one of which was found to be that very few studies were conducted comparing the efficacy of KTP lasers with other lasers in dental bleaching. One of the major drawbacks was that some articles did not have a proper mean value for shade and temperature measurement. Among the four studies, only the 3 seem to be uniform to some extent in terms of intervention comparison two used diode lasers,[7,11] two used Nd: YAG,[7,17] and one used Er: YAG.[18] Thus, more meticulous research is needed to be carried out in this direction where different concentrations of hydrogen peroxide are activated using KTP lasers for different exposure times, which may provide a lesser concentration of HP with laser activation for bleaching.

Clinical relevance

From these studies, it appears that using KTP lasers with hydrogen peroxide delivers better results compared to other laser systems. The outcomes are clearly more acceptable in terms of esthetics, and absence of undesirable outcomes such as temperature rise, morphological changes, and alteration in microhardness. The results of *in vitro* studies look promising. However, clinical studies of relevance are required to throw some more light on the topic.

We recommend clinical trials in which outcome measures must include long-term color stability, postoperative sensitivity, and effects of hydrogen peroxide used.

The use of activation devices reduce the contact time for which the bleaching agents come in contact with the tooth. The most commonly observed side effects of hydrogen peroxide bleaching are tooth sensitivity and gingival irritation, which are usually mild-to-moderate and transient. Tooth whitening is not associated with significant health risks; however, potential adverse effects can occur with inappropriate application, abuse, or the use of inappropriate whitening products.[26]

CONCLUSION

Based on the data obtained in the present review, the bleaching treatment protocol is directly related to the type of discoloration, activation of the bleaching agent, and esthetic requirement. Although all bleaching procedures were effective in color change, the KTP laser showed better results when compared to other types of laser activation for color change, least rise in intrapulpal temperature, negligible enamel surface change, and absence of change in microhardness.

Clearly, more research into using different concentrations of HP along with KTP laser activation with different exposure times can be undertaken.

Author contribution

- Dr. Aishwarya Sanjay Awati has reviewed the articles for the systematic review, data extraction, and risk of bias tool modification and manuscript writing
- Dr. Aishika Paul has reviewed the articles for the systematic review, data extraction, and risk of bias tool modification and manuscript writing
- Dr. Neha Dhaded, Dr. Sonal B Joshi, and Dr. Vasanti Lagali-Jirge have written and reviewed the manuscript and contributed to the risk of bias assessment.

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Conflicts of interest
There are no conflicts of interest.

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