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Systematic Review

Effectiveness of Laser-Assisted Teeth Bleaching: A Systematic Review

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Abstract: Objective: Esthetic dentistry is an important factor in increasing patients' quality of life. This study aimed to investigate the impact of laser use on bleaching procedures for natural teeth and dental restorative materials. Methods: In January 2024, an electronic search was conducted using PubMed, Web of Science (WoS), and Scopus databases with the keywords (tooth) AND (laser) AND (bleaching), following PRISMA guidelines and the PICO framework. The initial search yielded 852 articles, of which 441 were screened. After applying inclusion criteria, 376 articles were excluded as they did not focus on the use of lasers in bleaching natural teeth and restorative materials. Consequently, 40 articles were included in the final review. Results: Of the 40 qualified publications, 29 utilized a diode laser, of which 10 authors concluded that it increases the whitening effect comparing classical methods. Three of included publications investigated the whitening of dental materials, while another three focused on endodontically treated teeth. Whitening procedures on ceramics effectively removed discoloration, but the resulting color did not significantly differ from the initial shade. Conversely, composite materials not only failed to bleach but also exhibited altered physical properties, thereby increasing their susceptibility to further discoloration. The KTP laser demonstrated promising outcomes on specific stains. The Er,Cr:YSGG and Er:YAG lasers also showed beneficial effects, although there were variations in their efficacy and required activation times. Conclusions: The findings partially indicate that laser-assisted bleaching improves the whitening of natural teeth. Further research on the effect of laser bleaching on the physical parameters of restorative materials is necessary.

Keywords: dental lasers; dental restorative materials; laser-assisted whitening; tooth whitening; VITA shade guide

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1. Introduction

Tooth bleaching has become one of the most popular esthetic procedures performed in dental offices in recent years [1]. This surge in popularity is driven by patients' increasing desire not only for dental health but also for enhanced esthetics. White teeth are widely regarded as indicators of youth, social status, and health-consciousness [2]. Hydrogen peroxide (HP) is the most commonly used bleaching agent, at concentrations typically around 35% [3]. The mechanism of tooth bleaching involves a chemical oxidation reaction in which chromogenic compounds are oxidized and converted to colorless forms [4–6]. Despite its efficacy, conventional in-office bleaching with HP often necessitates multiple treatment sessions to achieve the desired results. This can lead to tooth sensitivity, which is a common side effect [7]. Furthermore, the outcomes of bleaching treatments are frequently unsatisfactory when it comes to dental restorations, such as composite resins and porcelain crowns. These materials often do not respond uniformly to bleaching agents, leading to discrepancies in color and overall esthetic results. Recent advancements have prompted the evaluation of laser-assisted bleaching as an adjunct to traditional methods. Laser technology has shown promise in enhancing the efficacy of bleaching agents by accelerating the chemical reactions involved. Various studies have explored the use of lasers to improve the speed and effectiveness of the whitening process. Additionally, lasers may help in achieving more uniform results across both natural teeth and restorative materials.

When planning the teeth whitening process for patients, it is crucial to recognize that the aforementioned bleaching agents will interact not only with the natural tissues of the tooth but also with various restorative materials commonly used in modern dentistry [8]. One of the most frequently used restorative materials is composite resin, which is a popular choice due to its esthetic properties and ease of application. It is important to assess how exposure to bleaching agents will influence the physical and chemical properties of these materials. Recent research has highlighted the impact of bleaching agents on the color and stability of composite resins, as achieving a brighter shade is a primary goal of whitening treatments. While hydrogen peroxide (HP) and carbamide peroxide (CP) are effective at whitening natural tooth tissues, their interaction with resin composites can be problematic. Studies have shown that these materials often do not respond to bleaching agents in the same manner as natural tooth tissues [8]. For instance, while natural teeth can exhibit significant color change, resin composites may experience limited or uneven color modification, which can lead to esthetic discrepancies between natural teeth and restorations. Resin composites, due to their organic matrix, are particularly susceptible to adverse effects from tooth whitening treatments. The oxidative hydrolysis induced by peroxides at the C-C bonds of the polymer matrix can lead to the degradation of the composite resin, causing discoloration, a loss of gloss, and structural weakening [4]. The integrity of the resin matrix can be compromised, leading to potential issues such as increased porosity and reduced bonding strength. Additionally, studies have found that repeated exposure to bleaching agents can exacerbate these issues, causing the progressive deterioration of the composite material over time. Some research also indicates that certain types of composite resins are more resistant to bleaching effects than others, suggesting that material composition and formulation play a significant role in the response to whitening treatments [8]. To address these concerns, it is essential to carefully select restorative materials that are compatible with whitening agents and to consider alternative or supplementary whitening strategies that minimize the impact on dental restorations.

The mechanisms behind laser-assisted tooth bleaching can be divided into two basic methods: photothermal and photochemical reactions (Figure 1). In the photothermal method, the laser acts as an activator and enhancer for the bleaching agent, typically hydrogen peroxide (HP) or carbamide peroxide (CP). The laser's energy increases the rate of the chemical reactions involved in the bleaching process by heating the bleaching agent, which enhances its effectiveness. This method can lead to the more efficient breakdown of chromogenic compounds and accelerated whitening [2,9]. In the photochemical method, laser light is absorbed by the bleached surfaces and directly induces the photooxidation of the chromogenic macromolecules. The energy from the laser light interacts with the pigment molecules, causing a chemical reaction that breaks down the color-producing compounds, resulting in a lighter shade of the tooth [10,11]. This method leverages the laser's ability to generate reactive oxygen species that interact with and degrade chromogenic molecules. Each laser used in these procedures is characterized by several critical parameters: the wavelength of the emitted light (measured in nanometers, nm), the power density of the beam (measured in watts per square centimeter, W/cm^2), and the type of energy emitted—whether pulsed or continuous [12,13]. Additional features include the pulse rate and pulse duration, which influence the overall effectiveness and safety of the procedure [2,9–11]. The choice of laser parameters can significantly affect the outcome of the bleaching treatment, as different wavelengths and power settings can result in varying levels of effectiveness and risk. The energy emitted by a laser must be meticulously controlled during in vivo tooth bleaching, as part of the beam is converted into heat. Excessive heat can increase the temperature of the tooth structure and the surrounding soft tissues, potentially leading to pulp damage, thermal injury, or discomfort [14,15]. Effective cooling mechanisms and the precise calibration of laser settings are essential to mitigate these risks and ensure the safety of the procedure [16,17].

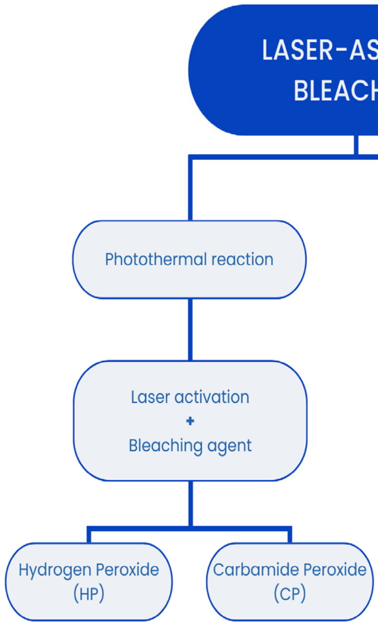

Figure 1. The mechanisms behind laser-assisted tooth bleaching.

The aim of this systematic review was to evaluate the role of laser-assisted teeth bleaching, considering its effectiveness on both dental restoration materials and natural teeth. After analyzing articles related to the use of laser irradiation to support the bleaching process, it was determined that a systematic review of this subject is justified. Currently, no systematic review on this topic has been published. Undertaking such a literature review could inspire researchers to conduct further studies, potentially yielding significant advantages for both dental practitioners and patients in the future.

2. Materials and Methods

2.1. Focused Question

The systematic review followed the PICO framework [18] as follows: In cases of dental bleaching (population) what would be the effect of laser use (investigated condition) on the color change (outcome) of teeth and different dental restorative materials compared to other bleaching methods (comparison condition)?

2.2. Protocol

The selection process for articles included in the systematic review was carefully outlined following the PRISMA flow diagram [19] (see Figure 2). The systematic review was registered on the Open Science Framework under the following link: https://osf.io/dvnh8 (accessed on 3 August 2024).

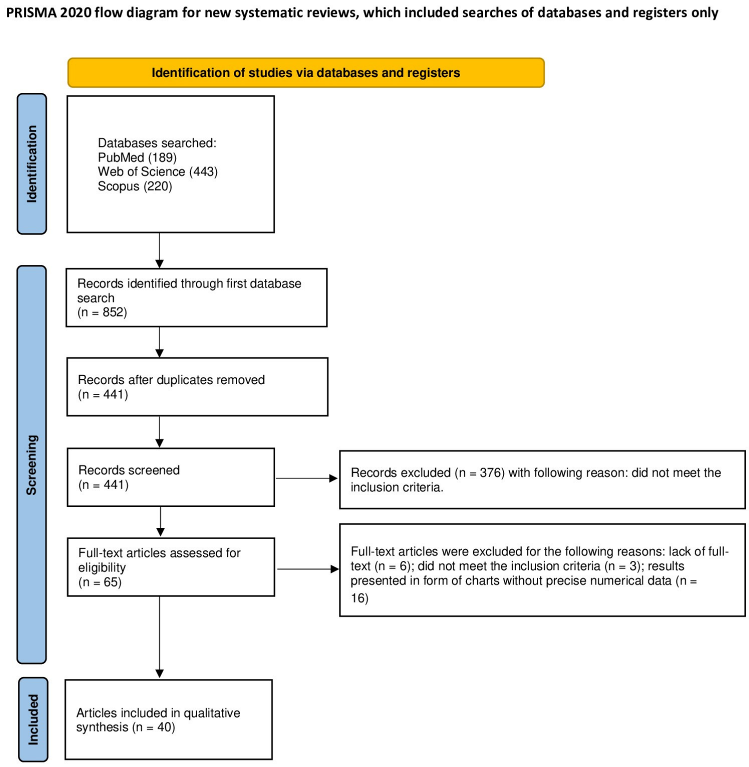

Figure 2. The PRISMA 2020 flow diagram.

2.3. Eligibility Criteria

The researchers agreed to include only the articles that met the following criteria [18,20–28]:

- Laser conditioning studies;
- Studies conducted on natural teeth or restorative materials;
- Color evaluation studies;
- In vitro studies;
- In vivo studies;
- Studies with a control group;
- Studies in English;
- Full-text articles.

The exclusion criteria the reviewers agreed upon were as follows [18,20–28]:

- No laser treatment;
- No color evaluation;
- Studies without a control group;
- Non-English papers
- Systematic review articles;
- Review articles;
- No full-text accessible;
- Duplicated publications.

No restrictions were applied with regard to the year of publication.

2.4. Information Sources, Search Strategy, and Study Selection

In January 2024, the PubMed, Scopus, and Web of Science (WoS) databases were searched to find articles meeting the specified inclusion criteria. To find articles focusing on laser bleaching's effect on natural teeth or restorative materials, the search was narrowed to titles and abstracts using a combination of key words: tooth AND laser AND bleaching. All searches conformed to the predefined eligibility criteria, and only articles with accessible full-text versions were taken into consideration.

2.5. Data Collection Process and Data Items

The articles that followed the inclusion criteria were carefully extracted by seven independent reviewers (J.K, B.P, M.Z.-D., W.Ś, J.K, S.K, W.D). The following data were used: first author, year of publication, study design, article title, laser application, and its bleaching effect. These essential data were entered into a standardized Excel file.

2.6. Risk of Bias and Quality Assessment

During the initial phase of study selection, each reviewer independently examined the titles and abstracts to mitigate potential reviewer bias. The Cohen's k test served as a tool to assess the extent of the agreement among reviewers. Any discrepancies regarding the inclusion or exclusion of an article in the review were addressed through discussion among the authors [29].

2.7. Quality Assessment

Two reviewers (J.M, M.D) conducted independent screenings of the included studies to assess the quality of each selected study. To evaluate the study's design, implementation, and analysis, the following criteria were used: a minimum group size of 10 subjects, the presence of a control group, a clear description of the performed bleaching method, the characteristics of the exposure time, an assessment of the bleaching effect, a description of the effect of bleaching on tooth tissue or surfaces, and the number of bleaching methods used. The studies were scored on a scale of 0 to 10 points, with a higher score indicating higher study quality. The risk of bias was assessed as follows: 0–4 points denoted a high risk, 5–7 points denoted a moderate risk, and 8–10 points indicated a low risk. Any discrepancies in scoring were resolved through discussion until a consensus was reached [18,20–28].

3. Results

3.1. Study Selection

An initial database search of PubMed, Scopus, and WoS yielded 852 articles potentially relevant to the review. After removing duplicates, 441 articles were screened. After the initial screening of titles and abstracts, 376 articles that did not concern laser-assisted teeth or restorative material bleaching were excluded. It was not possible to access the full text of six articles. Of the remaining 59 articles, 3 were excluded as they did not meet the inclusion criteria and 16 were excluded in which the research results were presented in the form of charts, without the possibility of reading precise numerical data. Ultimately, a total of 40 articles were included in the qualitative synthesis of this review. The considerable heterogeneity among the included studies prevents the possibility of conducting a meta-analysis.

3.2. General Characteristics of the Included Studies

The selected studies assessed the change in the color of teeth and dental materials as a result of carbamide peroxide (CP) and hydrogen peroxide (HP) whitening activated by laser light. To assess color, researchers most often used a spectrophotometer and its parameters using the CIE L*a*b* system. It is a color space created by the International Commission on Illumination (CIE) for the purpose of the standardization and repeatability of measurements. The L* axis contains shades of gray, numerically ranging from 0 to 100, where 0 is black and 100 is white. The a* axis is referred to as "red–green". At its negative end there are shades of red, and at its positive end there are shades of green. The b* axis, called "blue–yellow", is created analogously. The blue color is described by negative numbers, while the positive numbers are reserved for the yellow color. The tested color is described as a point in three-dimensional space. It is defined by three numerical values that change linearly. If two colors are written in the CIE L*a*b* color space, you can calculate the number ΔE (the number of the difference between the colors), which is the distance between these colors in the three-dimensional CIE L*a*b color space, using the formula ΔE* = (ΔL*2 + Δa*2 + Δb*2)1/2 [30,31]. Some authors also calculated the Whitening Index for Dentistry (WI_D) using the formula $WI_D = 0.511\ L^* - 2.324\ a^* - 1.100\ b^*$ [1,3]. Another system used is Vita Classical Shade Guide, where we deal with 16 shades arranged from the lightest B1 (1) to the darkest D4 (16). To calculate the difference in color change, the authors used numerical values corresponding to individual shades and called them Shade Guide Units (SGU) [32].

3.2.1. Diode Laser-Assisted Bleaching

Authors most often chose to use a diode laser for bleaching in their studies. This procedure appeared in as many as 29 papers [2–5,7–9,33–54]. In 11 of them, the in vitro whitening involved human teeth [34,35,37,40,42,45,47,50–52,55]. It was observed that when using 35% HP, the best whitening effects were achieved with a laser power of 1.5 W, regardless of whether the wavelength was 810, 940, or 980 nm [37,55,56]. For higher and lower power values, the results were not as significant [37,55,56]. When using CP as a bleaching agent, both Saluja et al. [35] and Nam et al. [46] proved that the effect was proportional to the CP concentration and exposure time. This relationship did not occur in the case of HP and bovine teeth [38,48]. The studies also included two publications in which the whitening agent was activated in the pulp chamber with a diode laser, and, in both cases, a more favorable effect was obtained at a shorter wavelength [33,43]. It was much more difficult to find relationships in the studies conducted in patients [2,5,7,41,44,49,54,57,58]. In these cases, very different wavelengths, concentrations of preparations, and methods for assessing the effects were used. For example, Mondelli et al. [54] used an 810 nm diode laser to activate materials containing 35% HP, 38% HP, and 15% CP. After exposing each material for 3 min, he concluded that they were equally effective [54]. However, effectiveness cannot be conclusively determined for whitening dental materials where the ΔE typically reaches a value less than 1, indicating that the color difference is not noticeable [8,36]. The exception is a study conducted by Mawlood AA and Hamasaeed NH [4], who whitened a composite restorative material (Filtek™, 3MESPE, Dental Product, St. Paul, MN, USA) with 40% HP activated by a 940 nm diode laser, achieving ΔE values of 5–10, which are comparable to those observed in enamel whitening [4]. Additionally, some publications included studies using hybrid light. Guedes et al. [3] reported that irradiation with an 808 nm diode laser combined with blue and violet LEDs increased whitening efficiency. In contrast, Costa et al. [9], who added a violet LED to an 810 nm diode laser, found that the effect was no different from using 35% HP without activation [9].

3.2.2. Gallium Aluminum Arsenate (AsGaAl) Laser-Assisted Bleaching

AsGaAl laser-assisted bleaching was conducted only by Vochikovski et al [1]. Its aim was to reduce post-treatment sensitivity, but the obtained result turned out to be statistically insignificant. The whitening effect was comparable to that without laser activation [1].

3.2.3. Neodymium/Yttrium–Aluminum–Garnet (Nd:YAG) Laser-Assisted Bleaching

The use of the Nd:YAG laser for whitening non-vital teeth has proven to be as effective as both a diode laser at 810 and 980 nm and the walking bleaching method [33]. In in vivo tooth whitening, the results were comparable to those achieved without activation. However, in vitro studies showed less tooth color change with Nd:YAG laser activation compared to halogen light [59,60]. Borse et al. [61] attempted to enhance the whitening effect by pre-treating the enamel with this laser before applying the whitening agent, but this approach did not yield the expected results [61].

3.2.4. Argon Laser-Assisted Bleaching

Lima et al. [62] performed bleaching using 35% HP and 37% CP and activation with various light sources, including an argon laser with a wavelength of 488 nm. The results showed that this laser produced the least color change of all the groups tested. Jones et al. [63] concluded that argon laser activation did not cause any color change, obtaining an average ΔE of 2.23 [63].

3.2.5. Potassium Titanyl Phosphate (KTP) Laser-Assisted Bleaching

There was a dissonance between researchers using the KTP laser. According to some studies, the effects are more visible compared to the diode laser, but the results of others indicate that there is no statistically significant difference between them [48,52]. Lagori et al. [53] point out the difference in action against specific discolorations. In their study comparing the effects of diode laser-assisted whitening and KTP, he showed that both lasers could remove coffee stains, while enamel stains caused by fruit and tea were only removed by using the KTP laser and not the diode laser [53].

3.2.6. Erbium/Yttrium–Aluminum–Garnet (Er:YAG) and Erbium, Chromium, Yttrium, Scandium, Gallium Garnet (Er,Cr:YSGG) Laser-Assisted Bleaching

Whitening with the assistance of an Er:YAG laser led to a change in the color of the enamel comparable to that achieved with a diode laser, but required twice the exposure time [55]. When applied to endodontically treated teeth, the Er:YAG laser provided a more favorable effect than the walking bleaching method, although this was only observed with the use of 20% HP [64]. Both Papadopoulos et al. [10] and Dionysopoulos et al. [55] prove, with their research, the effectiveness of Er,Cr:YSGG laser whitening. They both used 35% HP and the same laser parameters for this purpose. Papadopoulos additionally compared the power of 1.25 W and 2.5 W, while Dionysopoulos reduced the exposure time from 30 to 15 s. In each case, whitening was more effective than conventional methods. However, this does not work in the case of composite fillings. In this case, the obtained color did not differ from the initial one [8] (see Table 1).

Table 1. General characteristics of studies.

Study	Aim of the Study	Material and Methods	Results	Conclusions
Guedes RA [3]	Bleaching treatment using 37% carbamide peroxide combined with hybrid light and TiO_2 increases the effectiveness of the change in color of the dental surface.	Fifty bovine incisors were divided into 5 groups and exposed to 35% hydrogen peroxide, 37% urea peroxide, urea peroxide + hybrid light, urea peroxide 1% TiO_2, and urea peroxide + 1% TiO_2 + hybrid light.	The greatest color changes for ΔEab were observed after bleaching with urea peroxide + hybrid light, as well as urea peroxide + 1% TiO_2 + hybrid light. ΔE00 and ΔWID were higher with bleaching with urea peroxide + 1% TiO_2 + hybrid light.	A whitening gel containing carbamide peroxide combined with TiO_2 and hybrid light increases whitening effectiveness.
Mawlood AA [4]	The effect of 940 nm diode laser-activated bleaching on the color of dental composite filling materials.	Thirty samples were made from Filtek Bulk Fill, FiltekTM Z550 XT Universal Restorative, and FiltekTM Z350xt Flowable Composite. Each was then divided into 3 smaller groups: the control group, Laser White20, and Laser White20 with diode laser activation.	The greatest color change was observed in restorations made with FiltekTM Z350xt Flowable RBCs, regardless of whether laser activation was used or not.	Bleaching caused a slight change in the color of the composite materials and their roughness. Bleaching can cause a loss of bonding between the composite molecules and lead to the increased release of toxic monomers.
Vochikovski L [1]	Evaluation of photobiomodulation in reducing tooth sensitivity after in-office bleaching.	Patients were divided into a control group that received only 1 whitening session and an experimental group. Color was assessed using the VITA shade guide and a spectrophotometer.	There was no difference in the intensity of hypersensitivity. A significant change in the color of the whitened teeth was observed in both groups.	Photobiomodulation does not increase the risk of hypersensitivity after a whitening treatment.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Borse VS [61]	The aim of the study was to check if treating enamel with a Nd:YAG laser before the bleaching procedure influences the bleaching results.	Thirty incisors were stained with tea solution and divided into control and experimental groups, which were exposed to Nd:YAG laser. Then, all samples were bleached using 35% hydrogen peroxide.	The teeth became lighter in both groups, with no significant differences observed between them.	The use of a Nd:YAG laser before whitening does not affect the effectiveness of whitening with 35% hydrogen peroxide.
Shokouhinejad N [33]	Comparison of 3 laser assisted bleaching protocols with conventional walking bleach in terms of efficiency.	Seventy-two endodontically treated incisors were divided into 4 groups—the first was bleached only with 35% hydrogen peroxide gel, the second with 35% HP and a Nd:YAG laser, the third with 35% HP + 980 nm diode laser, and the last with 35% HP + 810 nm diode laser.	The whitening effects in each group were comparable and no significant difference was found between samples treated with 35% HP only and 35% HP + any laser.	In endodontically treated teeth, conventional whitening with 35% hydrogen peroxide is as effective as laser-assisted protocols.
Tekce AU [2]	Evaluation of diode laser- and LED-activated tooth bleaching treatments.	The dental arches of 32 patients were divided into two parts—one was bleached with 35% hydrogen peroxide and activated by an LED, and the other with 35% HP and activated by a diode laser (940 nm).	There was no significant difference in color change between the 2 protocols. The temperature change was greater with diode laser whitening. No significant difference in tooth and gum sensitivity was found.	There were no significant differences between bleaching protocols that were assisted by a diode laser or LED-activated, regarding color change.
Naik PL [34]	Comparison of home bleaching and laser-assisted bleaching using a spectrophotometer.	Forty teeth were divided into two groups. One underwent laser whitening, the other home whitening. Within each group, subgroups were distinguished based on the substance used to create the discoloration.	No significant difference in color change in tea-stained samples. The laser whitening results were better than the home whitening ones.	Laser-assisted bleaching was more effective than home bleaching in paan-stained teeth, while there was no significant difference between home and laser-assisted bleaching in tea-stained teeth.
Saluja I [35]	Comparison of effectiveness of tooth bleaching depending on the concentration of bleaching agent (carbamide peroxide) used, using or not-using a 980 nm laser, and a time of 2.5 or 5 min.	One hundred teeth were discolored with tea solution and divided into 4 groups: 1—control, 2—bleached with 15, 20, and 35% CP, 3—the same CP concentrations as group 2, but with activation by a 980 nm laser for 2.5 min, 4—as group 3, but with an activation time of 5 min.	The color after bleaching using 35% CP with a laser for 5 min was comparable to the effect of 15% CP activated for 2.5 min.	It was found that 35% CP works faster than its lower concentrations, but the final whitening effect is comparable to 15% CP. The laser allows for a faster whitening process, but the final results with and without the laser are similar.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Chitsaz F [36]	Spectrophotometer color and translucency evaluation of conventional and CAD-CAM porcelain materials after staining and bleaching assisted by a laser.	Seventy-two CAD-CAM and conventional feldspathic porcelain samples were divided into 3 groups—coffee-stained, orange juice-stained, and control groups. Then, a diode laser-assisted bleaching procedure was performed.	Coffee and orange juice cause a change in the color of the porcelain, which was less pronounced in the CAD/CAM-produced samples. Bleaching is effective for both types, but the maximum color that can be achieved is the pre-staining one.	Laser-assisted bleaching can be used to get rid of stains on the porcelain, but it does not cause a difference in baseline translucency or the shade of the material.
Karanasiou C [8]	Assessing the color alteration of three resin-based restorative materials following two in-office tooth bleaching procedures facilitated by Er,Cr:YSGG and diode (980 nm) lasers.	Nanohybrid composite resin (EP), Bis-GMA-free composite resin (EPBio), and CAD-CAM ceramic with resin matrix (HC) were divided into 3 groups. Group 1 was treated with 40% H_2O_2 only, while Groups 2 and 3 were activated with an Er,Cr:YSGG laser and diode laser (980 nm), respectively.	The color and whiteness changes were below the acceptability thresholds. EP showed the highest color change after bleaching, followed by EPBio and HC.	The bleaching treatments tested with the assistance of Er,Cr:YSGG and diode (980 nm) lasers did not cause undesirable color and whiteness changes in the resin-based restorative materials.
de Sousa Gomes Costa JL [9]	Bleaching and microstructural impacts of low-concentration hydrogen peroxide, photoactivated with an LED/laser system, on bovine enamel.	Twenty bovine incisors were divided into 2 groups: 6% HP + LED/laser and 35% HP. The teeth were stained with tea and then three whitening sessions were performed according to the manufacturer's instructions.	Color changes were observed in both groups, with the greatest seen in the 35% HP alone group. Significant differences were observed for Δa*, Δb*, ΔWID, and ΔE00, but not for ΔL*.	The 6% HP with an LED/laser produced noticeable color changes, but less than the 35% HP. There were no noticeable differences in enamel microhardness after the treatment; however, the 35% HP showed reduced hardness after 7 days compared to the baseline.
Papadodoulos A [10]	Spectrophotometric assessment of the efficacy of an Er,Cr:YSGG laser-assisted intracoronal tooth bleaching treatment employing various power settings.	Twenty-four endodontically treated canines were divided into three groups. Group 1 underwent intracoronal bleaching with 35% hydrogen peroxide (HP) gel for 40 min. Group 2 was treated as 1, but with Er,Cr:YSGG activation. Group 3 was treated as Group 2, but with modified laser parameters.	No significant difference in color change was seen between the three groups. The 2.5 W laser group showed a significantly higher ΔE than the control group after the first whitening session.	The final ΔE was not different compared to the control group, regardless of laser's power settings.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Ozer SY [64]	Comparison of whitening efficacy using carbamide peroxide (CP) or sodium perborate with 20% hydrogen peroxide (HP) with and without photon-induced photoacoustic streaming (PIPS) activation.	Eighty-five incisors were endodontically treated with sheep blood and divided into five groups: Group 1 (walking bleaching with CP), Group 2 (walking bleaching with sodium perborate–20% HP), Group 3 (PIPS + CP), Group 4 (PIPS + sodium perborate–20% HP), and Group 5 (control).	The PIPS + sodium perborate–20% HP group showed noticeably better whitening efficacy compared to the other groups.	The activation of sodium perborate–20% H_2O_2 with PIPS resulted in a better bleaching effect than that achieved with walking bleaching techniques or PIPS using carbamide peroxide.
Saeedi R [37]	Evaluation of the effectiveness of conventional bleaching in comparison to laser-assisted bleaching utilizing three distinct wavelengths of diode lasers.	Forty incisors were immersed in a solution of tea, coffee, and cola for 21 days and then divided into four groups: Group 1 (diode laser 810 nm + Biolase Laser White 20), Group 2 (diode laser 940 nm + Biolase Laser White 20), Group 3 (diode laser 980 nm + Biolase Laser White 20), and Group 4 (Opalescence Boost without laser activation).	The 940 nm laser group exhibited the highest bleaching efficacy, while the 810 nm laser group demonstrated the lowest efficacy. Nevertheless, there was no significant difference in bleaching efficacy between the two groups.	Laser bleaching utilizing diode lasers with wavelengths of 810 nm, 940 nm, and 980 nm demonstrates an efficacy comparable to conventional bleaching but achieves results in a shorter timeframe. No discernible difference was observed between various laser wavelengths regarding bleaching efficacy.
Ahrari F [44]	Evaluation of the efficacy and complications of several bleaching techniques in patients after orthodontic treatment.	Sixty people with teeth discoloration after orthodontic treatment were divided into 4 groups. Group 1 underwent home whitening and groups 2–4 received in-office whitening using a diode laser, plasma arc, and without a light source.	The color change was most significant in the home whitening group, followed by the in-office laser whitening group, and least significant in those treated with plasma arc whitening.	All methods have proven effective. Laser-assisted whitening emerges as the preferred option, providing effective results with minimal tooth sensitivity and in a shorter amount of time.
Al-Maliky MA [5]	Observation of the effectiveness of a 940 nm diode laser in conjunction with bleaching gel by assessing tooth sensitivity and color change.	Fourteen patients underwent laser-assisted bleaching using a 940 nm diode laser and a bleaching gel containing 38% hydrogen peroxide.	The scores ranged from 5 (A2) to 16 (C4) before treatment and from 6 (C1) to 1 (B1) after whitening. This change was statistically significant.	The change in tooth brightness after treatment was significant.
Bersezio C [39]	Evaluation of color stability after 2 years of whitening with a blue LED or laser-activated whitening gel, comparing 6% hydrogen peroxide (HP) with 35% HP.	A total of 131 participants with incisor color A2 or darker without fillings or enamel damage underwent whitening.	All values showed a color difference between the groups after 1 week and one month and at a 2-year follow-up.	Despite significant differences in effectiveness, the clinical impact was not evident to patients due to the perceptibility threshold of human vision when comparing two similar colors.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Ergin E [55]	Comparison of an Er:YAG laser-activated whitening system with various light-activated whitening systems.	Fifty-one bovine incisors were divided into 3 groups: a diode laser group, Er:YAG group, and LED group.	All whitening methods proved effective, with no statistically significant differences between them.	All mentioned bleaching systems are effective when used with 35% H_2O_2, with an E value above 3.3.
Dionysopoulos D [65]	Evaluation of the Er,Cr:YSGG laser-assisted tooth whitening method and its comparison with the traditional method.	Spectrophotometric analysis of color change of 24 bovine incisors, with crowns separated from the roots.	Both the length of time of the bleach application and activation with Er,Cr:YSGG laser influenced the effectiveness of the treatment. Laser-treated groups showed greater color change.	The Er,Cr:YSGG laser-assisted tooth whitening treatment is more effective than a conventional whitening treatment in terms of the color change of teeth.
Fekrazad R [40]	Comparison of teeth whitening effectiveness using Opalescence Xtra Boost and LaserSmile gel activated by a diode laser.	Twenty fresh incisors were divided into 2 groups. In group 1, bleaching was performed using a diode laser activated 35% HP gel. In group 2, Opalescence Xtra Boost Gel containing 38% HP was used.	Laser whitening produced significantly better results than without activation, both increasing whiteness and reducing the degree of the yellowing of the teeth.	Laser bleaching can be used to reduce operation time and increase patient comfort and mobility during bleaching procedures. Also, it is a safer remedy compared to power bleaching with 38% hydrogen peroxide gel.
Vildosola P [41]	Comparison of two different in-office bleaching protocols using 6% peroxide.	Thirty patients were treated, half of the arch of their teeth with traditional application protocols and other with abbreviated protocols, both activated with blue light.	Both treatments were effective, with no significant differences.	Both approaches were equally effective.
Mena-Serrano AP [7]	Comparison of bleaching efficacy and tooth sensitivity of two hydrogen peroxide protocols used for IOB, associated, or not, with a light-emitting diode LED/laser light activation.	Seventy-seven patients with a right canine from maxilla darker than A3 were selected. Patients were distributed in four groups. Their tooth color was evaluated each week and 30 days afterwards using the VITA Classical Shade Guide.	Significant whitening was observed in both study groups with best results for 35%+ Light.	A higher degree of whitening was shown when 20% HP gel when supplementary light was used and when evaluated using VITA shades; however, with a spectrophotometer there was no significant difference.
Bhutani N [42]	Evaluation of the role of light and laser sources in the bleaching ability of 37.5% HP on extracted human tooth.	Thirty incisors were divided into three groups: 37.5%HP, 37.5%HP + laser activation, and 37.5%HP + light activation.	All groups shown significant differences in their mean shade value.	The laser showed the biggest ability to increase bleaching due to its activation of the bleaching molecules.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Al-Karadaghi TS [43]	Evaluation of the effectiveness of tooth whitening with activation by a diode laser with a wavelength of 940 nm or 980 nm.	The root canals of 30 premolars were prepared and a 38% HP bleaching agent was applied. Then, photoactivation was performed using a 940 nm or 980 nm diode laser.	The mean increment in Vita shade in all groups followed the sequence of L940 > L980 > control group.	The largest color change was achieved when using the bleaching agent activated with the 940 nm diode laser.
Ahrari F [38]	Comparison of the effectiveness of laser-activated whitening and home whitening of healthy and demineralized enamel.	One hundred and twenty fresh bovine incisors without visible caries or structural defects on their enamel surface were stained and bleached.	There were significant differences in the color change between the study groups.	This study shows the effectiveness of whitening healthy and demineralized cattle teeth.
Kameda A [45]	To evaluate the effect of the acid etching of enamel and the subsequent combination of different light sources and a whitening product on color change and HP penetration.	Ninety six enamel/dentin discs were divided into eight groups and their color was assessed using a spectrophotometer before the first whitening treatment, 6 days after each whitening treatment, and 14 days after the end of the treatment period.	All groups showed a progressive and continuous change in color, the use or lack of use of light did not influence the color change obtained in different periods.	This study shows that the bleaching treatment with a high concentration of H_2O_2 was effective regardless of the use of light.
Nam SH [46]	Assessment of the tooth whitening effect using non-thermal plasma at atmospheric pressure (NAPP).	Forty teeth were divided into 4 groups: Group I (CP + NAPP), Group II (CP + plasma arc lamp; PAC), Group III (CP + diode laser), and Group IV (CPE).	In the CP + NAPP group, the whitening effect was the best and the tooth surface temperature was approximately 37 °C, while in the other groups it increased to 43 °C.	NAPP has a greater ability to effectively whiten teeth than conventional low-HP light sources without causing thermal damage. In the future, this may be the most frequently used method in office whitening.
Polydorou O [57]	Assessment of color stability after whitening using a halogen lamp, laser, or no activation.	Sixty patients were divided into 3 groups and their teeth were whitened with 38% HP using 3 methods: halogen lamp activation, laser activation, or no activation.	Immediately after whitening, activation with a halogen lamp gave the best effect. After 1 and 3 months, no significant difference was found.	The use of light to accelerate the process of bleaching is not important for esthetic results with regard to long-term whitening effects.
Hahn P [47]	Assessment of color stability after whitening activated with a halogen light, laser, LED unit, or chemical up to 3 months after the procedure.	Eighty teeth were divided into 4 groups and whitened with Opalescent Xtra Boost using four different activation methods: halogen lamp, LED, laser, or without additional activation.	Activation with a halogen lamp caused the greatest change in color. Regardless of the type of activation, teeth were whiter after 1 and 3 months.	The use of light activation showed no advantages compared to chemical bleaching.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Al Quaran F [58]	Assessment of the effectiveness of laser whitening using various schemes and color stability over a period of 6 months.	Sixty patients were divided into 3 groups and underwent diode laser whitening with the addition of 34% HP. Group 1: one whitening session. Group 2: 2 sessions. Group 3: 2 sessions + home whitening.	All teeth changed color significantly after 6 months, but there was a regression in color immediately after whitening. In group 3, much less color regression was observed.	The combination of in-office and home whitening techniques gives better results in the long run.
Fornaini C [48]	Comparison of whitening with a 532 nm KTP laser and an 808 nm diode laser to investigate the relationship between changes in gel temperature, tooth shade, and HP concentration.	One hundred and sixteen bovine teeth were whitened using 30% HP gel, some with the gel itself and others with gel activated by a KTP or diode laser of two different powers (2 and 4 W).	A significant effect and minimal temperature increase were obtained using the KTP laser. The diode laser caused a larger temperature increase and the color change was statistically significant only at 4 W.	No statistically significant relationship was found between temperature, HP concentration, and tooth shade change. The KTP laser provides better results with a safe increase in temperature.
Gurgan S [49]	Assessment of the effectiveness of in-office whitening systems using various light sources in terms of the color change and possible side effects seen, such as tooth hypersensitivity and gum irritation.	Forty people with A3 teeth were divided into 4 groups. Group 1 underwent whitening without light activation; group 2 with diode laser activation; group 3 with a plasma arc lamp; and group 4 with a diode (LED) lamp.	All whitening techniques proved effective, with the color change being greatest after diode laser activation.	In-office whitening systems are effective both with and without light. Diode laser whitening causes less sensitivity of the teeth and gums, which is why it may be preferred among the in-office whitening systems available.
Strobl A [59]	Assessment of the teeth whitening effect of a Nd:YAG laser.	In-office laser whitening was performed on 20 patients using a neodymium/yttrium–aluminum–garnet (Nd:YAG) laser. Each patient underwent two treatments 1 week apart.	A change in tooth shade was observed in both the laser-activated and control quadrants. There was no statistically significant difference in hue between quadrants.	These study results give us a reason to consider the practicality of using the Nd:YAG laser in teeth whitening.
Lima D [50]	Assessment of tooth whitening effectiveness and color stability.	Enamel blocks were divided into 15 groups. The whitening agents used were 35% HP and 37% CP and they were activated by a halogen lamp and plasma arc lamp, LED/diode laser, and argon laser, or not activated.	A better effect was obtained using HP; however, the samples became discolored after a month, whereas the color obtained after bleaching with CP was stable.	The halogen lamp had the same or higher effectiveness than whitening without activation. When hydrogen peroxide was used, discoloration was observed 30 days after the end of bleaching.
Marcondes M [60]	Assessment of tooth color change during whitening with hydrogen peroxide activated by Nd:YAG lasers of various wavelengths or halogen light.	The 150 tooth samples were divided into 5 groups: WL (H_2O_2 and Nd:YAG), WH (H_2O_2 and halogen light), QL (HP carbopol Q-switch and Nd:YAG), QH (HP carbopol Q-switch and halogen light), and C (control, without bleaching agent).	The shade changed by seven levels for the Nd:YAG laser groups and eight levels for halogen light.	The Nd:YAG laser in combination with hydrogen peroxide bleached the enamel; the shade was similar to that obtained with the traditional method performed using halogen light.

Table 1. *Cont.*

Study	Aim of the Study	Material and Methods	Results	Conclusions
Gontijo IT [51]	In vitro evaluation of 2 primary teeth whitening techniques in terms of changes in color and surface temperature during tooth whitening using various catalytic sources.	Twenty-one primary incisors were stained with human blood and divided into 2 groups: (1) diode laser (DL) activation and (2) halogen lamp (HL) activation.	The same level of whitening was obtained with the use of the laser and halogen lamp. However, the temperature was higher with the halogen lamp.	There was no significant difference between groups in color change, but there was a significant difference in temperature change. The diode laser showed a smaller increase in temperature compared to the halogen lamp.
Zhang C [52]	Evaluation of the effectiveness of whitening with a light-emitting diode (LED), a diode laser, and a KTP laser, taking into account the change in color, temperature in the pulp chamber, and enamel microhardness.	Sixty-four incisors were bleached with HP activated with an LED, a 980 nm diode laser, or a 532 nm KTP laser.	Whitening induced by the KTP laser had a significantly better effect. The average maximum increase in pulp temperature was 2.95 °C for the LED laser, 3.76 °C for the KTP laser, and 7.72 °C for the diode laser, respectively.	The KTP laser effectively whitens teeth. Under the conditions used in this study, the LED laser and KTP resulted in a safer increase in pulp temperature when assisted with Hi-Lite whitening gel.
Jones A [63]	Assessing color change of three tooth bleaching techniques, including laser-activated hydrogen peroxide and two concentrations of carbamide peroxide.	Forty human central incisors underwent argon laser-activated whitening with 35% H_2O_2 or 10% or 20% carbamide peroxide. The control group did not undergo any bleaching.	The laser-activated group was not statistically different from the control group. The color difference in the 10% and 20% CP groups was statistically different from the control group.	Exposure to 20% carbamide peroxide produced the greatest bleaching effect. The recommended one-time application of laser-activated hydrogen peroxide did not demonstrate any color change.
Lagori G [53]	Evaluation of the whitening effectiveness of two different lasers (KTP and diode 810 nm).	One hundred and thirty-five bovine teeth were discolored in a tea, coffee, or red fruit solution and divided into 3 groups. One was bleached with a 30% HP gel, the second was additionally irradiated with an 810 nm diode laser, and the last with a KTP laser.	The diode laser was effective only at bleaching teeth stained with coffee, while the KTP laser was efficient at bleaching teeth with coffee, tea, and red fruit stains.	There is a relationship between the laser wavelength, the type of discoloration on the tooth enamel, and the effectiveness of the whitening treatment.
Mondelli RFL [54]	Assessment of color change, its stability, and post-treatment sensitivity after teeth whitening using various methods.	Patients were divided into groups: G1: 35% HP + hybrid light (HL) (LED/diode laser); G2: 35% HP; G3: 38% HP + HL; G4: 38% HP; and G5: 15% CP. Groups 1–4 had 3 in-office bleaching treatments, while Group 5 received home bleaching.	There was no statistically significant difference between office whitening with or without HL activation, but in the HL-irradiated groups the procedure time was shorter. In-office whitening increased tooth sensitivity.	All compared methods were equally effective.

3.3. Main Study Outcomes

A diode laser was used in 29 publications, of which 10 concluded that it increases the whitening effect [5,34,38,40,42,43,48,52,53,55]. Of the four publications in which the Nd:YAG laser was used, only one showed its positive effect on whitening [59]. In two out of three tests conducted using the Er,Cr:YSGG laser, a greater color change was found compared to the conventional method [8,10,55]. None of the studies involving argon or AsGaAl lasers showed that they increased whitening efficiency [1,62,63]. At the same time, the authors of all articles describing whitening assisted with KTP or Er:YAG lasers concluded that they increased the whitening effect [48,52,53,55,64]. In 31 papers, a spectrophotometer was used to measure color, of which only 1 decided not to calculate the ΔE value [1–4,7–10,33–41,44,46,48,49,51–56,61,63–65]. As many as seven researchers decided to use the VITA shade guide as the only assessment of whitening effects [5,42,43,47,57,58,60]. The bleaching of ceramics typically results in the restoration of their original factory color, with no significant improvement beyond that [36]. Moreover, bleaching composite materials has generally yielded limited or no noticeable color improvement [4,8]. For whitening endodontically treated teeth, laser-assisted techniques have demonstrated superior efficacy compared to conventional methods, as shown in two studies [43,64]. Furthermore, lasers have been effective in whitening non-vital primary teeth, presenting a promising alternative to traditional approaches [51]. Among the whitening agents, 35% hydrogen peroxide (HP) was the most commonly used, featured in 17 of the 40 studies reviewed [1,2,7,10,37,40,45,51,52,54,55,59–61,63,65,66]. (See Table 2.)

Table 2. Detailed characteristics table.

Authors	Bleaching Material and Bleaching Surface	Laser Type	Laser Parameters	Color before Bleaching	Color after Bleaching	Color Difference
Guedes RA [3]	37% carbamide peroxide (CP) Bovine enamel in vitro	Diode laser 808 nm + blue LED 450 nm + violet LED 405 nm	Time: 1 min Distance: 2 cm Power: 100 mW + 390 mW + 375 mW Continuous Wave (CW)	VITA Classical = 11.20(0.92) L = 86.55 (4.47) a = 1.95 (0.20) b = 34.08 (2.78)	VITA Classical = 3.50 (2.92) L = 93.11 (2.74) a = 0.45 (−0.90; 1.90) b = 21.57 (3.06)	ΔE = 14.55 (2.02) ΔWID = 19.88 (3.03)
Mawlood AA [4]	40% hydrogen peroxide (HP) FiltekTM Bulk Fill composite resin (B) FiltekTM Z550 XT universal restorative (U) FiltekTM Z350 XT flowable composite (F)	Diode laser 940 nm	Time: 30 s Distance: 1 mm Power: 1.5 W CW	No data	No data	ΔE(B) = 5.827 (1.232766) ΔE(U) = 8.901 (1.189402) ΔE(F) = 9.611 (0.949087)
Vochikovski L [1]	35% HP Enamel in vivo	AsGaAl 808 nm	Time: 30 s Power: 100 mW Surface area: 3–6 mm^2 Fluence: 100 J/cm^2	SGU VITA Classical = 10.1 ± 3.1	No data	ΔSGU VITA Classical = 3.4 ± 2.3 ΔE = 8.7 ± 4.1 ΔWID = 12.0 ± 8.7
Borse VS [61]	35% HP Enamel in vitro	Nd:YAG	Time: 60 s Distance: 1 cm Power: 1 W Frequency: 15 Hz	L = 46.615 a = 2.709 b = 13.368	L = 59.013 a = 1.845 b = 10.615	ΔL = 12.397 Δa = −0.865 Δb = −2.753 ΔE = 12.739
Shokouhinejad N [33]	35% HP Teeth treated endodontically in vitro	Nd:YAG Diode laser 810 nm Diode laser 980 nm	Time: 30 s Distance: - Power: 2.5 W, 2 W(diode) Frequency: 25 Hz, CW(diode)	Lack of precise data	Lack of precise data	Nd:YAG ΔE = 21.17 ± 10.71 Diode laser 980 ΔE = 18.94 ± 5.33 Diode laser 810 ΔE4 = 20.66 ± 8.12

Table 2. *Cont.*

Authors	Bleaching Material and Bleaching Surface	Laser Type	Laser Parameters	Color before Bleaching	Color after Bleaching	Color Difference
Tekce A [2]	35% HP Enamel in vivo	Diode laser 940 nm	Time: 30 s Distance: 1 mm Power: 7 W Surface area: 4.86 cm^2 Power Density: 1.44 W/cm^2 CW	VITA Classical A2 or darker	No data	ΔSGU = 5.6 ± 2.2 ΔE = 4.2 ± 3.1
Naik PL [34]	37% HP Enamel in vitro	Diode laser 980 nm	Time: 30 s CW	No data	No data	ΔE = 28.376
Saluja I [35]	35% CP 15% CP 20% CP Enamel in vitro	Diode laser 980 nm	Time: 2.5 or 5 min Power: 5 W CW	15% CP + 2.5 min 29.14 (4.24) 20% CP + 2.5 min 27.69 (0.53) 35% CP + 2.5 min 30.20 (2.80) 15% CP + 5 min 29.06 (4.05) 20% CP + 5 min 27.64 (3.30) 35% CP + 5 min 30.27 (2.91)	15% CP + 2.5 min 24.38 (3.03) 20% CP + 2.5 min 26.08 (4.89) 35% CP + 2.5 min 23.65 (3.30) 15% CP + 5 min 25.55 (4.54) 20% CP + 5 min 24.92 (4.14) 35% CP + 5 min 20.57 (2.45)	15% CP + 2.5 min ΔE = 4.66 (5.13) 20% CP + 2.5 min ΔE = 3.52 (5.76) 35% CP + 2.5 min ΔE = 5.59 (5.85) 15% CP + 5 min ΔE = 7.32 (1.90) 20% CP + 5 min 7.71 (4.01) 35% CP + 5 min 10.61 (2.74)
Chitsaz S [36]	40% HP Vitablocs Mark II (Mark II) Vita VMK Master (VMK Master)	Diode laser 940 nm	Time: 30 s Power: 7 W CW	No data	No data	ΔE for VMK master immersed in orange juice = 1.67 (0.98) ΔE for Mark II immersed in orange juice = 0.42 (0.27) ΔE for VMK master immersed in coffee 3.18 (1.12) ΔE for Mark II immersed in coffee 0.73 (0.25)
Karanasiou C [8]	40% HP Enamel plus HRi (EP) Enamel plus HRi Bio Function (EPBio) Shofu Block HC (HC)	Er,Cr:YSGG 2780 nm Diode laser 980 nm	Time: 15 s Distance: 2.5 cm Power: 1.25 W Beam diameter: 800 µm Frequency: 10 Hz Time: 30 s Distance: 2 cm Power: 3.5 W Surface area: 1 cm^2 CW	EP L = 66.48 (2.09) a = 1 (0.06) b = 4.21 (0.41) EPBio L = 66.66 (2.79) a = 0.29 (0.41) b = 7.02(1.28) HC L = 67.58 (0.4) a = 1.5 (0.12) b = 8.43 (0.07)	EP + Er.Cr:YSGG L = 67.75 (2.15) a = 1.08 (0.32) b = 3.42 (0.98) EPBio + Er.Cr:YSGG L = 68.17 (2.72) a = 0.29 (0.42) b = 7.23 (1.14) HC + Er.Cr:YSGG L = 68.73 (0.43) a = 1.57 (0.11) b = 8.76 (0.12) EP + diode L = 68.09 (1.99) a = 1.21 (0.27) b = 3.67 (1.01) EPBio + diode L = 67.97 (3.03) a = 0.34 (0.34) b = 6.99 (1.37) HC + diode L = 68.3 (0.23) a = 1.48 (0.05) b = 7.84 (0.44)	EP + Er.Cr:YSGG *ΔE* = 2.11 (0.97) EPBio + Er.Cr:YSGG *ΔE* = 1.40 (0.63) HC + Er.Cr:YSGG *ΔE* = 0.81 (0.43) EP + diode *ΔE* = 2.09 (1.30) EPBio + diode *ΔE* = 1.14 (0.63) HC + diode *ΔE* = 0.81 (0.48)
Costa J [9]	6% HP Bovine enamel in vitro	Diode laser 810 nm + violet LED 405 nm	Time: 1 m Power: 300 mW + 2400 mW CW	No data	No data	ΔL = 10.34 ± 3.65 Δa = −3.73 ± 1.41 Δb = −12.1 ± 1.69 ΔE = 9.92± 2.08

Table 2. *Cont.*

Authors	Bleaching Material and Bleaching Surface	Laser Type	Laser Parameters	Color before Bleaching	Color after Bleaching	Color Difference
Papadopoulos A [10]	35% HP Enamel in vitro	Er,Cr:YSGG 2780 nm	Time: 30 s Distance: 2.5 cm Power: 1.25; 2.5 W Beam diameter: 800 µm Frequency: 10 Hz Fluence: 0.45 J/cm^2; 0.9 J/cm^2	No data	No data	For 1.25 W ΔE = 23.90 ± 7.42 ΔL = 21.52 ± 7.47 Δa = − 7.71 ± 2.47 Δb = − 6.23 ± 2.17 For 2.5 W ΔE = 30.97 ± 6.47 ΔL = 29.23 ± 6.43 Δa = − 8.20 ± 2.57 Δb = − 5.45 ± 1.93
Ozer SY [64]	20% HP, 37% CP Endodontically treated teeth	Er:YAG 2940 nm	Time: 1 min Power: 0.9 W Beam diameter: 300 µm Frequency: 30 Hz Fluence: 30 mJ/pulse	No data	No data	For CP ΔE = 6.796(0.675) For HP ΔE = 9.598(1.148)
Saeedi R [37]	35% HP Enamel in vitro	Diode laser 810 nm Diode laser 940 nm Diode laser 980 nm	Time: 30 s Distance: 1 mm Power: 1.5 W Surface area: 1 cm^2 CW	Diode laser 810 nm L = 65.76 ± 10.68 a = 0.78 ± 2.19 b = 17.18 ± 8.28 Diode laser 940 nm L = 59.04 ± 11.32 a = 3.36 ± 4.53 b = 21.93 ± 10.24 Diode laser 980 nm L = 61.15 ± 8.43 a = 3.21 ± 3.73 b = 17.41 ± 9.05	Diode laser 810 nm L = 74.86 ± 8.12 a = 1.44 ± 1.48 b = 13.22 ± 7.93 Diode laser 940 nm L = 66.60 ± 3.83 a = 0.640 ± 1.86 b = 8.89 ± 8.19 Diode laser 980 nm L = 65.62 ± 4.31 a = 0.73 ± 2.02 b = 11.42 ± 6.42	Diode laser 810 nm ΔE = 21.23 ± 5.39 Diode laser 940 nm ΔE = 28.58 ± 6.72 Diode laser 980 nm ΔE = 23.76 ± 8.33
Ahrari F [44]	46% HP Enamel in vivo	Diode laser 810 nm	Time: 30 s Power: 3 W Power density: 4.2 W/cm^2 CW	VITA Classical = D2 or darker	No data	ΔE = 7.52 ± 6.45
Al-Maliky MA [5]	38% HP Enamel in vivo	Diode laser 940 nm	Time: 30 s Distance: 1 mm Power: 7 W Surface area: 2.8 cm^2 Power density: 2.5 W/cm^2 Fluence: 75 J/cm^2 CW	VITA Classical = 8.29	VITA Classical = 2	No data
Bersezio C [39]	6% HP Enamel in vivo	Diode laser + blue LED	Time: 12 min Power: 300 mW CW	SGU VITA Classical = 5 (5.11) L = 84.08 ± 4.64 a = −0.34 ± 1.61 b = 24.19 ± 4.37	No data	ΔSGU VITA Classical = 4 (3/10) ΔE = 6.15 ± 4.77
Ergin E [55]	35% HP Enamel in vitro	Diode laser 940 nm Er:YAG 2940 nm	Time: 30 s Distance: 1 mm Power: 7 W CW Time: 60 s Distance: 2 cm Power: 7 W Frequency: 10 Hz	No data	No data	Diode ΔE = 8.43 ± 3.04 Er:YAG ΔE = 9.04 ± 7.57

Table 2. *Cont.*

Authors	Bleaching Material and Bleaching Surface	Laser Type	Laser Parameters	Color before Bleaching	Color after Bleaching	Color Difference
Dionysopoulos D [65]	35% HP Enamel in vitro	Er,Cr:YSGG 2780 nm	Time: 15 s Distance: 2.5 cm Power: 1.25 W Beam diameter: 800 um Fluence: 0.45 J/cm^2 Frequency: 10 Hz	No data	No data	ΔE = 16.02 ± 2.85 ΔE with double irradiation time = 17.03 ± 2.32
Fekrazad R [40]	35% HP Enamel in vitro	Diode laser 810 nm	CW	No data	No data	ΔE = 3.05 ± 1.459 ΔL = 2.32 ± 1.9362
Vildósola P [41]	6% HP Enamel in vivo	Diode laser 810 nm	Time: 12 min Power: 600 mW Surface area: 8.5 cm^2 Power density: 300 mW/cm^2 CW	VITA Classical = 9 (A3) L= 81.94 (4.47) a = 0.96 (1.07) b = 24.66 (3.40)	No data	ΔSGU = 6 ΔE = 5.06 (3.26) ΔL = 2.04 (4.09) Δa = 0.38 (0.83) Δb = 1.75 (3.57)
Mena-Serrano AP [7]	20% HP 35% HP Enamel in vivo	Diode laser 830 nm	Time: 1 min Power density: 200 mW/cm^2 CW	20% SGU = 12 35% SGU = 11	No data	20% ΔE = 11.8(4) ΔSGU = 7.9(1.8) 35% ΔE = 14.5(3.5) ΔSGU = 8.2(1.2)
Bhutani N [42]	37.5% HP Enamel in vitro	Diode laser 810 nm	Time: 9.9 s Power: 7 W CW	SGU = 13.20(3.26)	No data	ΔSGU = 7.60(4.93)
Al-Karadaghi TS [43]	38% HP Teeth treated endodontically	Diode laser 940 nm Diode laser 980 nm	Time: 120 s Distance: 1 mm Power: 7 W Surface area: 4.86 cm^2 Power density: 1.44 W/cm^2 Fluence: 43.20 J/cm^2 CW Time: 120 s Distance: 1 mm Power: 7 W Surface area: 2.9 cm^2 Power density: 2.41 W/cm2 Fluence: 72.30 J/cm^2 CW	No data	No data	940 ΔSGU = 8.4 (1.71) 980 ΔSGU = 6.4 (2.41)
Ahrari F [38]	40% HP Bovine enamel in vitro	Diode laser 810 nm	Time: 60 s Distance: 1 mm Power: 2 W CW	L = 86.08 (8.14) a = 0.75 (2.41) b = 27.86 (7.01)	L = 95.05 (4.30) a = −0.74 (1.60) b = 17.89 (4.04)	ΔE = 13.97 (7.11)
Kameda A [45]	35% HP Enamel in vitro	Diode laser 808 nm	Time: 3 min Power: 0.2 W CW	No data	No data	Without etching ΔE = 6.07(1.03) With etching ΔE = 7.79 (2.22)
Nam S [46]	15% CP Enamel in vitro	Diode laser 980 nm	Time: 10 or 20 min Power: 0.5 W Beam diameter: 350 µm CW	No data	No data	10 min ΔE = 4.24 ± 0.81 20 min ΔE = 5.52 ± 0.87
Polydorou O [57]	38% HP Enamel in vivo	Diode laser 980 nm	Time: 30 s Power: 6 W CW	No data	No data	ΔSGU = 2.15 (6 2.4)

Table 2. *Cont.*

Authors	Bleaching Material and Bleaching Surface	Laser Type	Laser Parameters	Color before Bleaching	Color after Bleaching	Color Difference
Hahn P [47]	38% HP Enamel in vitro	Diode laser 980 nm	Time: 30 s Power: 6 W CW	No data	No data	ΔSGU = 1.8 ± 2.6
Al Quran F [58]	34% HP Enamel in vivo	Diode laser 815 nm	No data	3D-Master VITA shade guide = 9.35 (1.87)	3D-Master VITA shade guide = 3.65 (1.50)	No data
Fornaini C [48]	30% HP Bovine enamel in vitro	KTP laser 532 nm Diode laser 808 nm	Time: 30 s Power: 2, 4 W	No data	No data	KTP 4 W ΔE = 3.43 ± 1.24 KTP 2 W ΔE = 3.68 ± 1.63 Diode ΔE = 3.43 ± 1.24
Gurgan S [49]	37% HP Enamel in vivo	Diode laser 810 nm	Time: 8 min Power: 10 W CW	No data	No data	ΔE = 5.69 ± 0.172 ΔL = 5.5 ± 0.131 Δa = −1.3 ± 0.007 Δb = −1.9 ± 0.157
Strobl A [59]	35% HP Enamel in vivo	Nd:YAG 1064 nm	Time: 30 s Power: 4 W Beam diameter: 6 mm Fluence: 1.4 J/cm^2 Frequency: 10 Hz	ShadeEye NCC Color Scale = 6.6 SGU = 6.9	ShadeEye NCC Color Scale = 3.9 SGU = 2.5	No data
Lima D [50]	35% HP 37% CP Enamel in vitro	Diode laser 830 nm Argon laser 488 nm	Time: 3 min Power: 200 mW CW Time: 30 s Power: 200 mW	Diode Laser Reflectance for HP group = 14.1 (0.6) Reflectance for CP group = 14.7 (0.8) Argon Laser Reflectance for HP group = 15.1 (0.5) Reflectance for CP group = 14.6 (1.0)	Diode laser Reflectance for HP group = 18.2 (0.4) Reflectance for CP group = 16.8 (0.7) Argon laser Reflectance for HP group = 18.2 (0.4) Reflectance for CP group = 16.5 (0.7)	No data
Marcondes M [60]	35% HP Enamel in vitro	Nd:YAG	Time: 2 min Power: 2.5 W Fluence: 79.62 J/cm^2 Frequency: 25 Hz	SGU = 11.43 (B3)	SGU = 14.23 (D2)	No data
Gontijo IT [51]	35% HP Enamel of deciduous teeth in vitro	Diode laser 808 nm	Time: 30 s Distance: 1 mm Power: 1 W Beam diameter: 400 µm Power density: 0.85 W/cm^2 CW	L= 95.77 ± 2.17 C = 1.466 ± 0.577 VITA 3D color scale = 17.55 ± 5.61	L = 97.77 ± 1.52 C = 1.593 ± 1.274 VITA 3D color scale = 5.09 ± 3.24	ΔL = 2.00 ± 2.01 ΔC = 0.127 ± 1.300 ΔVITA 3D color scale = 12.45 ± 4.57
Zhang C [52]	35% HP	Diode laser 980 nm KTP laser 532 nm	Time: 30 s Distance: 1 cm Power: 1 W Fluence: 13.33 J/cm^2 CW	No data	No data	Diode laser ΔE = 5.74 (2.04) ΔL = 4.96 (1.98) Δa = 1.37 (0.56) Δb = –2.38 (1.12) KTP ΔE = 8.79 (3.05) ΔL = 8.35 (2.72) Δa = 0.87 (0.34) Δb = –3.10 (1.46)

Table 2. *Cont.*

Authors	Bleaching Material and Bleaching Surface	Laser Type	Laser Parameters	Color before Bleaching	Color after Bleaching	Color Difference
Jones A [63]	35% HP Enamel in vitro	Argon laser	Time: 30 s Distance: 1–2 cm	No data	No data	ΔE = 2.23 (0.25)
Lagori G [53]	30% HP Enamel of bovine teeth	KTP laser 532 nm Diode laser 810 nm	Time: 30 s Distance: 10 cm Power: 1.5 W Beam diameter: 8 mm	No data	No data	KTP ΔE = 7.740 (3.381) Diode laser ΔE = 5.873 (4.111)
Mondelli R [54]	35% HP 38% HP 15% CP Enamel in vivo	Diode laser 810 nm	Time: 3 min Power density: 200 mW/cm^2 CW	No data	No data	35% HP ΔE = 7.80 + 1.42 38% HP ΔE = 7.83 + 1.39 15% CP ΔE = 9.80 + 1.75

3.4. Quality Assessment

Among the articles included in the review, eleven [1,3,5,8,9,37,40,41,45,60,61] were rated as high-quality, achieving a score between 8 and 10 points out of 10. One study [34] was categorized as low-quality. Furthermore, twenty-eight studies [2,4,7,9,10,33,36,38,39,42–44,46–55,57–59,63–65] were identified as having a moderate risk of bias, scoring between 5 and 7 points (see Table 3).

Table 3. Quality assessment of reviewed articles. The full titles of some of the columns in Table 3 are given here. Column 7: evaluation of the bleaching effect (spectrophotometry/visual assessment using VITA coloring). Column 8: description of the effect of bleaching on teeth or dental materials (0 pts—no data/1 pt—before or after bleaching procedure/2 pts—information before and after bleaching procedure). Column 9: the number of bleaching methods used (1 laser/1 solution concentration/1 wavelength—1 point; ≥2 lasers/solutions/wavelengths—2 points).

Authors	Group Size of at Least 10 Subjects	Sample Size Calculation	Control Group	Detailed Description of the Bleaching Method	Exposure Time Characteristics	Evaluation of the Bleaching Effect (Spectrophotometry/Visual Assessment Using VITA Coloring)	Description of the Effect of Bleaching on Tooth or Materials	The Number of Bleaching Methods Used	Total	Risk of Bias
Guedes RA [3]	1	0	1	1	1	1	2	2	9	low
Mawlood AA [4]	1	0	1	1	0	1	0	1	5	moderate
Vochikovski L [1]	1	1	1	1	1	1	1	1	8	low
Borse VS [61]	1	0	1	1	1	1	2	1	8	low
Shokouhinejad N [33]	1	0	0	1	1	1	0	2	6	moderate
Tekce A [2]	1	1	0	1	1	1	1	1	7	moderate
Naik PL [34]	1	0	0	0	1	1	0	1	4	high
Saluja I [35]	1	0	1	1	1	1	2	1	8	low
Chitsaz S [36]	1	1	1	1	1	1	0	1	7	moderate
Karanasiou C [8]	1	1	1	1	1	1	2	2	10	low

Table 3. *Cont.*

Authors	Group Size of at Least 10 Subjects	Sample Size Calculation	Control Group	Detailed Description of the Bleaching Method	Exposure Time Characteristics	Evaluation of the Bleaching Effect (Spectrophotometry/Visual Assessment Using VITA Coloring)	Description of the Effect of Bleaching on Tooth or Materials	The Number of Bleaching Methods Used	Total	Risk of Bias
Costa J [9]	1	1	1	1	1	1	0	2	8	low
Papadopoulos A [10]	0	1	1	1	1	1	0	1	6	moderate
Ozer SY [64]	1	0	1	1	1	1	0	2	7	moderate
Saeedi R [37]	1	1	1	1	1	1	2	2	10	low
Ahrari F [44]	1	0	0	1	1	1	1	1	6	moderate
Al-Maliky MA [5]	1	1	0	1	1	1	2	1	8	low
Bersezio C [39]	1	1	1	1	1	1	1	1	8	low
Ergin E [55]	1	1	0	1	1	1	0	2	7	moderate
Dionysopoulos D [65]	1	1	0	1	1	1	0	1	6	moderate
Fekrazad R [40]	1	0	0	1	1	1	0	1	5	moderate
Vildósola P [41]	1	1	1	1	1	1	1	1	8	low
Mena-Serrano AP [7]	1	1	0	1	1	1	1	1	7	moderate
Bhutani N [42]	1	0	0	1	1	1	1	1	6	moderate
Al-Karadaghi TS [43]	1	0	1	1	1	1	0	2	7	moderate
Ahrari F [38]	0	0	1	1	1	1	0	1	5	moderate
Kameda A [45]	1	0	0	1	1	1	1	1	6	moderate
Nam S [46]	1	0	1	1	1	0	0	1	5	moderate
Polydorou O [57]	1	0	0	1	1	1	0	1	5	moderate
Hahn P [47]	1	0	0	1	1	0	0	2	5	moderate
Al Quran F [58]	1	0	0	0	0	1	2	1	5	moderate
Fornaini C [48]	1	0	0	1	1	1	0	2	6	moderate
Gurgan S [49]	1	0	0	1	1	1	0	1	5	moderate
Strobl A [59]	1	0	0	1	1	1	2	1	7	moderate
Lima D [50]	1	0	1	1	1	1	2	2	9	low
Marcondes M [60]	1	0	1	1	1	1	2	1	8	low
Gontijo IT [51]	1	0	0	1	1	1	1	2	7	moderate
Zhang C [52]	1	0	1	1	1	0	0	2	6	moderate
Jones A [63]	1	0	1	1	1	0	0	2	6	moderate
Lagori G [53]	1	0	1	1	1	1	0	2	7	moderate
Mondelli R [54]	1	0	1	1	1	1	0	2	7	moderate

4. Discussion

In this systematic review, we aimed to evaluate the efficacy of various laser wavelengths in bleaching procedures used for both natural teeth and restorative materials in comparison to traditional methods. Our findings suggest that laser-assisted bleaching can enhance the whitening effect for both natural teeth and dental restorative materials. A diode laser, with wavelengths ranging from 808 nm to 980 nm, was the most frequently utilized laser in these studies. [2–5,7–9,33–54]. Ten studies employing a diode laser concluded that its use enhances the whitening effect [5,34,38,40,42,43,48,52,53,55]. Interestingly, it was observed that when using 35% hydrogen peroxide, the best whitening effects were achieved with a laser power of 1.5 W, regardless of whether the wavelength was 810 nm, 940 nm, or 980 nm [37,55,56]. For higher and lower power values, the results were not significant [37,55,56]. Three papers focused on the laser-assisted bleaching of restorative materials. However, the differing methodologies and various variables assessed in these studies create difficulties in comparing the results. The use of the Nd:YAG laser for whitening non-vital teeth has proven to be as effective as 810 nm and 980 nm diode lasers [33]. Moreover, the results of two studies by Papadopoulos et al. [10] and Dionysopoulos et al. [55] demonstrated the effectiveness of Er,Cr:YSGG laser whitening with the application of 35% hydrogen peroxide.

Among the included papers, there were significant differences regarding the rationale for using laser-assisted activation in whitening procedures. Guedes et al. [3] reported that irradiation with an 808 nm diode laser combined with blue and violet LEDs increased whitening efficiency. In contrast, Costa et al. [9], who added a violet LED to an 810 nm diode laser, found that the effect was no different from using 35% HP without activation [3,9]. Ahrari et al. [38], Fekrazad et al. [40], and Al Maliky et al. [5] agreed that diode lasers with wavelengths of 810 and 940 nm not only shortened the whitening time but also reduced post-treatment sensitivity. Ergin et al. [55] achieved a better whitening effect by activating 35% HP with an Er:YAG laser than with a 940 nm diode laser, but the difference in the ΔE was less than 1, which means that it was not visually noticeable. However, according to Ergin et al. [55], it is still worth using the Er:YAG laser if the teeth require restoration after whitening, because they observed a better adhesion of materials to the whitened surfaces. However, the studies of Kiryk et al. [67] show that the Er:YAG laser leads to damage of the enamel surface. Ozer et al. [64] used this laser for the intracoronal whitening of endodontically treated teeth. A better effect is visible here than in the walking bleaching technique using 20% HP. Bahuguna [68] wrote that heating 30% HP promotes the development of external cervical resorption; the question arises as to whether the use of 20% HP with an Er:YAG laser will result in a lower risk of this common complication.

Other lasers discussed in this review include argon, Nd:YAG, and KTP lasers. The analysis of the compiled results indicates that the argon laser produced the least effective outcomes. Despite using bleaching agents such as 35% HP and 37% CP and a laser wavelength of 488 nm, its effect was not significantly visible. This may indicate insufficient laser power, meaning that it does not contribute to permanent enamel discoloration [62]. Other lasers, such as AsGaAL, Nd:YAG, or KTP lasers, did not show a better effect than the diode laser [1,33,48,53,59–61]. However, it is worth noting that, according to some studies, the KTP laser performs better on tea or fruit stains compared to the diode laser. This may indicate its superiority over the diode laser, as the spectrum of discolorations it affects appears to be somewhat broader [53].

Another important aspect is the irradiation time of the bleached surface. Studies show that increasing the laser irradiation time increases the bleaching effect. This effect can be said to increase proportionally, and with a twofold increase in time the effect doubles [35]. We must remember that during bleaching, the use of a laser only activates the chemical agent, which is crucial to the whole process. When using CP as a bleaching agent, both Saluja et al. [35] and Nam et al. [46] proved that the effect was proportional to the CP's concentration and exposure time. There is no such relationship with HP [38,48]. According to the studies of Mondelli et al. [54], when bleaching teeth in patients, the use of 15% CP gives the same result as using 35 or 38% HP. Much better results, presented as ΔE, were obtained using lasers with shorter wavelengths. Studies conducted by Shokouhinejad N. et al. [33] and Saeedi R. et al. [37] compared the bleaching effect of diode lasers with different wavelengths—810, 940, and 980 nm. Analyzing these two studies, one can conclude that the bleaching effect increases with the decrease in the wavelength of the assisting laser, presented in both studies as ΔE. The difference between the shortest and the longest wavelength is up to 7 units, which translates into a bleaching effect and enamel color change [37,56]. Similar conclusions can be drawn by considering other studies, where examples with shorter wavelengths produced better bleaching effects than those with longer wavelengths [41].

Some studies combined the use of diode lasers and LED light [3,9,39]. The results of these studies show that LED light can additionally enhance the effect of the bleaching on enamel. For the purpose of this review, we can compare the study conducted by Guedes et al. [3], which used additional LED light, with the study by Loiola et al. [69], which only used a diode laser with the same wavelength of 808 nm. Despite slight differences in laser parameters and the use of different bleaching agents, a significantly better bleaching effect can be observed for the diode laser combined with LED light, where the ΔE reaches up to 14 units [3]. Additionally, the use of LED light helps achieve a similar bleaching effect to that obtained at high concentrations even at low concentrations of the bleaching agent [9,38].

However, the other factors, apart from the tooth color itself, which should be taken into account and were not included in most of the studies are intriguing. When looking for the positive effects of lasers, it is worth paying attention to the aforementioned hypersensitivity caused by whitening. Browning et al.'s [70] study shows that as many as 77% of patients experience hypersensitivity within 2 weeks of teeth whitening, which indicates that this is a very important clinical aspect. Silva Casado et al. [71] and Kikly et al. [72] addressed this topic and both showed that laser activation does not reduce post-treatment hypersensitivity.

In the literature on whitening dental materials, authors have discussed different aspects of the materials, making it difficult to directly compare their findings. Mawlood and Hamasaeed [4] analyzed color stability and concluded that as a result of whitening, the physical parameters of the composites change, causing their surface to become rough and increasing their water sorption, which makes them more susceptible to discoloration. The authors made an intriguing observation that changes in composite parameters are influenced by the amount of filler within the material. The bleaching of composites was also performed by Karanasiou et al. [8], and they concluded that it did not affect the color of resin-based restorations. Conversely, Chitsaz et al. [36], studying ceramics, concluded that these materials are susceptible to discoloration from specific substances used in their experiments, such as coffee and orange juice. However, samples soaked in distilled water after bleaching did not show any change in color compared to their initial state, indicating that bleaching does not alter the inherent color of the ceramics.

The significant heterogeneity of the included studies does not allow for a meta-analysis. However, to obtain more accurate results and to be able to proceed to a meta-analysis, additional studies are needed that are homogeneous in terms of the laser types used and their parameters. There is no doubt that the number of publications describing the whitening of dental materials is so small that it is impossible to draw reliable conclusions for use in clinical practice. Nevertheless, considering the influence of laser light on the physical parameters of these materials, as demonstrated by Mawlood and Hamasaeed [4], this topic should be investigated in more detail in order to ensure the safety of whitening procedures for patients and to avoid complications harmful to oral health.

5. Conclusions

The reviewed studies partially demonstrate that laser-assisted bleaching significantly influences the color change seen in natural teeth. Among the various lasers evaluated, the diode laser showed the most consistent positive effects on bleaching outcomes, especially when used in combination with LED light, and lasers with shorter wavelengths generally provided better results. Certain lasers, such as the KTP laser, demonstrated promising outcomes on specific stains; others, like the argon laser, proved less effective. The Er,Cr:YSGG and Er:YAG lasers also showed beneficial effects, though with some variations in their efficacy and required activation times. Overall, laser-assisted bleaching enhances whitening results, but further research is crucial to refine the protocols used and achieve more consistent and dependable outcomes.

In summary:

- The diode laser demonstrated the most consistent positive effects on bleaching outcomes.
- The Er:YAG laser has a more beneficial effect on endodontically treated teeth, thanks to the possibility of using a lower HP concentration compared to the walking bleaching method.
- When assisting whitening with a diode laser, it is more beneficial to use a shorter wavelength.
- Laser-activated bleaching reduces post-treatment hypersensitivity.
- Laser bleaching may have an adverse effect on the physical parameters of restorative materials. This requires further in-depth study.

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