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Systematic Review

SEM Studies Assessing the Efficacy of Laser Treatment for Primary Teeth: A Systematic Review

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Abstract: Treating and limiting caries among young children are crucial issues for pediatric dentistry. In our systematic review, the authors intend to assess alterations in the surfaces of primary teeth following laser treatment using Scanning Electron Microscopy (SEM). The aim of this article is to systematically review and consolidate existing knowledge regarding the use of SEM imaging to assess the efficacy of laser treatment for primary teeth. On 10 November 2023, an electronic search was systematically conducted across PubMed, Cochrane, Web of Science, and Scopus databases with keywords ((laser) AND ((primary teeth) OR (deciduous teeth)) AND (SEM)). The initial pool consisted of 205 records, from which 93 duplicates were eliminated. After careful examination of the remaining articles, 24 records were included in this systematic review. The majority of articles suggest that laser treatment provides dentinal surface without a smear layer, enhances remineralization of enamel, and improves the bonding quality of resin restorations. However, some discrepancies are still present. Based on the gathered articles, the authors of this review have concluded that laser treatment could be applied to deciduous teeth in terms of caries treatment and remineralization although further research is still needed.

Keywords: laser; primary teeth; deciduous teeth; SEM

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1. Introduction

The maintenance of oral health in patients with primary dentition is a critical determinant influencing the developmental trajectory and subsequent condition of permanent teeth in children. Globally recognized by the World Health Organization, dental caries stands as a predominant public health challenge, reigning as the most prevalent noncommunicable disease [1]. The impact of caries spans diverse age groups among children, encompassing both primary and permanent dentition. The ongoing evolution of the most efficacious methods for prevention and treatment remains paramount. Nevertheless, traditional approaches may prove impractical for treating children's teeth under certain circumstances, notably in cases of limited patient compliance. Propelled by technological progress, contemporary systems offer a myriad of methodologies, tools, and techniques for caries removal [2]. Laser utilization constitutes one such technique. The effectiveness of treatment interventions can be judiciously evaluated through the application of Scanning Electron Microscopy (SEM).

The management of primary dentition demands a tailored approach attuned to the distinctive needs and anatomical intricacies inherent in young patients. Significantly, the tissues constituting primary teeth, namely, enamel and dentin, manifest reduced thickness when juxtaposed with their permanent counterparts. Furthermore, the enamel of primary teeth exhibits diminished mineralization and a more pronounced prismless layer [3,4]. This distinctive tissue composition of deciduous dentition renders it notably more prone to caries development compared to permanent teeth, owing to its lower mineral and higher organic contents [5–7]. Pulp chambers in primary teeth exhibit proportionately augmented dimensions and closer proximity to the tooth surface. Clinical crowns of primary teeth are characterized by reduced height, and any potential cavities tend to present with wider and shallower dimensions [8]. Factors conducive to the accelerated onset of caries in primary teeth encompass attributes such as barrel-shaped crowns, expansive and planar contact surfaces of molars, and diminished mineralization of hard dental tissues [9].

Scanning electron microscopy (SEM) has emerged as an indispensable tool across diverse research disciplines, furnishing microscopic insights into the surface or near-surface characteristics of specimens [10]. Its application extends to the meticulous assessment of cavity preparation, facilitating the elucidation of the state of the smear layer and dentinal tubules [2]. Moreover, within the scientific literature, SEM images are employed for discerning the presence or absence of bacterial deposits [11]. The analytical potential of SEM proves instrumental in identifying areas of dentin resorption and the colonization of microorganisms. Notably, this method was judiciously applied to scrutinize root canals and furcation areas, specifically in a study addressing the complexities surrounding pulpectomy failure in primary teeth [12].

Erbium-doped yttrium aluminium garnet (Er:YAG) laser irradiation is posited as a potentially advantageous approach for caries removal or cavity preparation in primary teeth, primarily due to its purported minimal impact on pulp and surrounding tissues [13]. Furthermore, the Er:YAG laser demonstrates effectiveness in reducing microbial pathogens [14]. A comprehensive study comparing various caries removal methods [2] found no statistically significant differences in mineral densities at the cavity floors. These methods encompassed mechanical rotary and non-rotating systems, chemo-mechanical systems, and the Er:YAG laser. Notably, the authors underscored that although the orifices of the tubules remain unopened after laser treatment, the exposure of markedly rough surfaces may influence the bond strength of the filling [2]. The strategic use of carbon dioxide, argon, and neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers in clinical practice emerges as an effective approach for caries prevention. For instance, the application of an erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser without water cooling led to increased calcium and phosphorus contents, enhancing enamel resistance to demineralization. However, the sustained preventive efficacy of this method awaits long-term substantiation, with the recommendation of acidulated phosphate fluoride gel to complement this form of prevention [15]. The lasers commonly utilized for caries treatment or prevention are depicted in Figure 1.

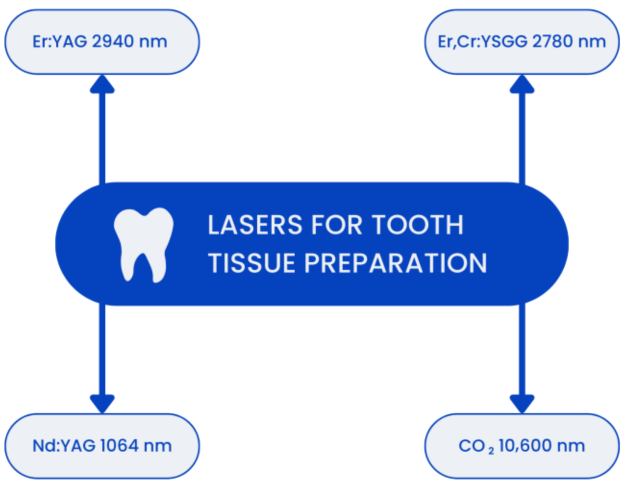

Figure 1. Lasers used for the preparation or conditioning of dental tissues.

Dental caries is a pervasive issue, especially among children with primary dentition, and novel methods for its management are continuously under development. Known properties of lasers and effects of their use on dental tissues prompt speculation that lasers could be a suitable alternative to traditional caries treatment in deciduous teeth. However, the topic needs to be summarized and results from various studies compared to draw specific conclusions regarding whether lasers are indeed suitable treatment for tissues of primary dentition. The aim of this study is to systematically review and consolidate existing knowledge in the scientific literature regarding the use of SEM imaging to assess the efficacy of laser treatment for primary teeth. The authors intend to assess the alterations in the surfaces of primary teeth following laser treatment using SEM. This study sought to evaluate the null hypothesis suggesting that there is no discernible difference in the surface alterations of primary teeth when utilizing different laser systems as observed through Scanning Electron Microscopy (SEM) imaging. Given the absence of a systematic review on this specific topic in the searched databases, it is deemed essential to systematically address this gap.

2. Materials and Methods

2.1. Focused Question

The systematic review adhered to the PICO framework, outlined as follows:

PICO question: In the case of primary teeth (population), will the observation of Scanning Electron Microscopy (SEM) imaging after laser treatment (investigated condition) demonstrate alterations in the treatment's efficacy (outcome) compared among various employed laser systems (comparison condition)?

2.2. Protocol

The selection process for articles in the systematic review was carefully outlined following the PRISMA flow diagram (Figure 2).

2.3. Eligibility Criteria

The review includes articles that examine the efficacy of laser treatment of primary teeth assessed with SEM published in English. Studies were considered acceptable for inclusion in the review if they met the following criteria:

- Changes in the specified surfaces of human teeth were evaluated using an optical microscope and/or scanning electron microscope (SEM) and/or profilometers and/or micro-computed tomography (Micro-CT).
- Studies involving the use of lasers to irradiate tooth structures.
- In vitro studies
- Studies in English
- Clinical trials
- Non-randomized controlled clinical trials (NRS); and
- Randomized controlled clinical trials (RCT).

The reviewers excluded research that met the following standards:

- Non-English papers
- Clinical reports
- Opinions
- Editorial papers
- Review articles
- No full-text accessible
- Duplicated publications

There were no restrictions on the year of publication.

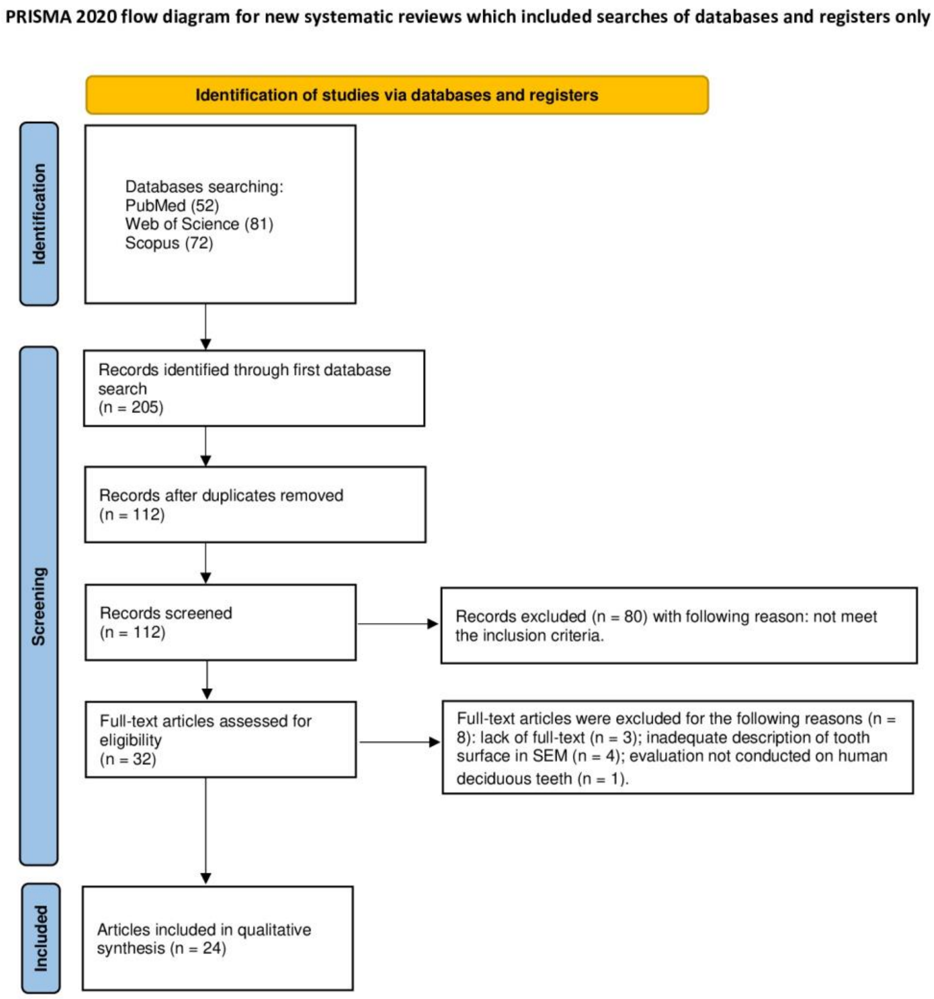

Figure 2. The PRISMA 2020 flow diagram.

2.4. Information Sources, Search Strategy, and Study Selection

On 10 November 2023, an electronic search was systematically conducted across PubMed, Cochrane, Web of Science, and Scopus databases. In PubMed and WoS, the search results were meticulously refined to encompass titles, authors, and abstracts, whereas in the Scopus database, the search was honed to titles, authors, and keywords. The search criteria were meticulously structured around the keywords ((laser) AND ((primary teeth) OR (deciduous teeth)) AND (SEM)). The eligibility criteria were predetermined by the researchers and involved individuals. Following the database search, an exhaustive literature review was systematically executed to identify any papers initially perceived as irrelevant to the study. Only articles with full-text versions were meticulously considered for inclusion.

2.5. Data Collection Process and Data Items

Five reviewers (N.S., K.W., J.K., A.P., P.J.P.) independently extracted data from articles that met the inclusion criteria. The extracted information was then entered into a standardized spreadsheet.

2.6. Risk of Bias and Quality Assessment

In the first stage of study selection, the titles and abstracts of each study were reviewed independently by the authors to minimize bias. Cohen's κ test was used to determine agreement between reviewers. Differences between the authors' concepts of inclusion or exclusion of articles were discussed between the reviewers.

2.7. Quality Assessment (QA)

Two independent reviewers (J.M., P.J.P.) systematically assessed the methodological quality of each study included in the article. The evaluation criteria were centered on the presence of relevant data regarding the efficacy of laser treatment for primary teeth, as assessed using SEM. Criteria encompassing the design, conduct, and analysis of the studies were considered, including a stipulated minimum group size of 10 subjects, the inclusion of a control group, the application of sample size calculations, a comprehensive description of laser parameters (power, frequency, wavelength, spot size, etc.), the irradiation protocol (distance, time, steps, etc.), and a detailed account of the treatment efficacy. Studies received scores on a scale ranging from 0 to 6, with higher scores indicative of superior study quality. The assessment of bias risk followed a categorization where 0–2 points signaled a high risk, 3–4 points suggested a moderate risk, and 5–6 points indicated a low risk. Any discrepancies in scoring were meticulously resolved through discussion until a consensus was achieved.

3. Results

3.1. Study Selection

The electronic database search yielded 205 records, from which 93 duplicates were eliminated, resulting in 112 records for abstract screening. After excluding 80 articles based on their abstracts, 32 articles remained for full-text evaluation. Three articles were excluded due to the unavailability of full-text versions. Following a thorough analysis of the full texts, four articles were excluded due to insufficient or absent surface characterization, and one was excluded because the experiment was not conducted on human deciduous teeth, leaving 24 articles for both qualitative and quantitative analysis.

3.2. General Characteristics of the Included Studies

This systematic review includes studies evaluating the effectiveness of laser treatment of primary teeth in which researchers analyzed data using SEM. Thirteen articles [2,13,16–26] assessed the influence of the Er:YAG laser, six [15,27–31] assessed the Er,Cr:YSGG laser, and five [32–36] assessed the Nd:YAG laser. Two of the articles [22,23] analyzed SEM images of both enamel and dentin, twelve [2,13,16,17,20,21,24,26,27,30,35,36] analyzed dentin images only, and ten [15,18,19,25,28,29,31–34] solely images of the enamel surface. Among other assessed parameters were shear bond strength in six articles [17,21,23–25,36] and microleakage in three articles [13,27,31]. Two articles each examined hybrid layer thickness [27,30], remineralization of enamel [28,33], and thermal effects on the pulp [22,29]. One article each assessed demineralization of enamel [15], bacterial adhesion [19], and microhardness [34] (see Table 1).

Table 1. General characteristics of the included studies.

Type of Laser		
Er:YAG	**Er,Cr:YSGG**	**Nd:YAG**
Duruk et al. [2] Kohara et al. [13] Flury et al. [16] Wang et al. [17] Kahvecioglu et al. [18] Teutle-Coyotecatl et al. [19] Guler et al. [20] Bahrololoomi et al. [21] Al-Batayneh et al. [22] Memarpour et al. [23] Monghini et al. [24] Wanderley et al. [25] Zhang et al. [26]	Ulusoy et al. [15] Öznurhan et al. [27] Yilmaz et al. [28] Almaz et al. [29] Öznurhan et al. [30] Arslan et al. [31]	Neto et al. [32] Asl-Aminabadi et al. [33] Banda et al. [34] Guglielmi et al. [35] Bolukbasi et al. [36]

Table 1. *Cont.*

<table>
<tr><th colspan="4">SEM Images</th></tr>
<tr><th>Dentin</th><th colspan="2">Enamel</th><th>Dentin + Enamel</th></tr>
<tr><td>Duruk et al. [2]
Kohara et al. [13]
Flury et al. [16]
Wang et al. [17]
Guler et al. [20]
Bahrololoomi et al. [21]
Monghini et al. [24]
Zhang et al. [26]
Öznurhan et al. [27]
Öznurhan et al. [30]
Guglielmi et al. [35]
Bolukbasi et al. [36]</td><td colspan="2">Ulusoy et al. [15]
Kahvecioglu et al. [18]
Teutle-Coyotecatl et al. [19]
Wanderley et al. [25]
Yilmaz et al. [28]
Almaz et al. [29]
Arslan et al. [31]
Neto et al. [32]
Asl-Aminabadi et al. [33]
Banda et al. [34]</td><td>Al-Batayneh et al. [22]
Memarpour et al. [23]</td></tr>
<tr><th colspan="4">Other Parameters</th></tr>
<tr><th>Shear Bond Strength</th><th>Microleakage</th><th>Hybrid Layer Thickness</th><th>Remineralization of Enamel</th></tr>
<tr><td>Wang et al. [17]
Bahrololoomi et al. [21]
Memarpour et al. [23]
Monghini et al. [24]
Wanderley et al. [25]
Bolukbasi et al. [36]</td><td>Kohara et al. [13]
Öznurhan et al. [27]
Arslan et al. [31]</td><td>Öznurhan et al. [27]
Öznurhan et al. [30]</td><td>Yilmaz et al. [28]
Asl-Aminabadi et al. [33]</td></tr>
<tr><th>Thermal Effects on the Pulp</th><th>Demineralization of Enamel</th><th>Bacterial Adhesion</th><th>Microhardness</th></tr>
<tr><td>Al-Batayneh et al. [22]
Almaz et al. [29]</td><td>Ulusoy et al. [15]</td><td>Teutle-Coyotecatl et al. [19]</td><td>Banda et al. [34]</td></tr>
</table>

3.3. Main Study Outcomes

3.3.1. Dentin Surface Characterization

When observing the dentin surface under SEM, several studies (Öznurhan et al. [27], Duruk et al. [2], Flury et al. [16], Wang et al. [17], Guler et al. [20], Bahrololoomi et al. [21], Memarpour et al. [23], Monghini et al. [24], Zhang et al. [26], Kohara et al. [13]) have found irregularities after use of the Er:YAG laser. However, only Öznurhan et al. [27] reported irregularities after use of the Er,Cr:YSGG laser. There is disagreement among authors regarding the patency of dentinal tubules. Duruk et al. [2] reported closed dentinal tubules when treated with the Er:YAG laser, while Flury et al. [16], Al-Batayneh et al. [22], Wang et al. [17], Öznurhan et al. [30], Memarpour et al. [23], Zhang et al. [26], and Kohara et al. [13] observed open (completely or partially) and exposed dentinal tubules after working with either the Er:YAG or Er,Cr:YSGG lasers. Bahrololoomi et al. [21] described an improvement in surface smoothness and more open dentinal tubules when additionally using NaOCl 5.25%. Wang et al. [17] have established a correlation between the energy level and frequency settings of the laser used. Higher laser settings result in greater disorganization of collagen fibers, signs of carbonization, and collapsed structure. The authors described another parameter, which is the presence or absence of a smear layer. Studies by Öznurhan et al. [30], Al-Batayneh et al. [22], Memarpour et al. [23], Zhang et al. [26], Kohara et al. [13], and Bolukbasi et al. [36] have reported no smear layer after laser use. Bahrololoomi et al. [21] observed a slight smear layer that can be completely removed with the use of 5.25% NaOCl (see Table 2).

Table 2. Dentin surface characterization.

Dentin Surface Irregularities	
Er:YAG Laser	**Er,Cr:YSGG Laser**
Duruk et al. [2] Kohara et al. [13] Flury et al. [16] Wang et al. [17] Guler et al. [20] Bahrololoomi et al. [21] Memarpour et al. [23] Monghini et al. [24] Zhang et al. [26] Öznurhan et al. [27]	Öznurhan et al. [27]
Patency of Dentinal Tubules	
Open (Completely or Partially)	**Closed**
Kohara et al. [13] Flury et al. [16] Wang et al. [17] Al-Batayneh et al. [22] Memarpour et al. [23] Zhang et al. [26] Öznurhan et al. [30]	Duruk et al. [2]
Presence of Smear Layer	
Present	**Absent**
Bahrololoomi et al. [21]	Kohara et al. [13] Al-Batayneh et al. [22] Memarpour et al. [23] Zhang et al. [26] Öznurhan et al. [30] Bolukbasi et al. [36]

3.3.2. Enamel Surface Characterization

Treating the enamel surface with Nd:YAG [32–36], Er,Cr:YSGG [15,28,29,31], or Er:YAG [18,19,22,23,25] lasers results in a rough, irregular surface, cracks, craters, and ablation areas in the tissue. This is supported by the findings of Ulusoy et al. [15], Yilmaz et al. [28], Almaz et al. [29], Asl-Aminabadi et al. [33], Kahvecioglu et al. [18], Teutle-Coyotecatl et al. [19], Al-Batayneh et al. [22], Memarpour et al. [23], Banda et al. [34], Wanderley et al. [25], and Arslan et al. [31]. According to Wanderley et al. [25], the irregularity of the enamel surface increases with higher frequency and energy settings in used lasers. Several articles that assessed the enamel surface under SEM focused on the usage of fluoride before or after laser treatment to improve the evenness of the surface. Neto et al. [32], Asl-Aminabadi et al. [33], and Banda et al. [34] agreed that the smoothness was greater with the use of fluoride. Ulusoy et al. [15] reported an image of a honeycomb with a cloudy surface in the fluoride-treated group. Banda et al. [34] compared sequences of such treatment and reported better results when treating enamel with a laser first and then applying fluoride than the other way around. Ulusoy et al. [15] stated that the craters that appeared after laser treatment were deeper in primary teeth than in permanent dentition.

3.4. General Study Outcomes

The authors Öznurhan et al. [27], Duruk et al. [2], Flury et al. [16], Memarpour et al. [23] agreed that laser treatment of primary teeth gives similar or better results than conventional methods. In the primary dentition, according to Al-Batayneh et al. [22], the Er:YAG laser outperforms the conventional high-speed diamond bur in the removal of carious tooth structure. The use of Er:YAG lasers has also been successful in terms of microleakage. According to Kohara et al. [13], cavities prepared with the Er:YAG laser have irregular surfaces but show less microleakage after filling with composite resin. Similar results were obtained by Arslan et al. [31] and Öznurhan et al. [27]. Neto et al. [32] stated that the demineralization of primary tooth enamel was inhibited for a period of one year without significant morphological changes, and studies by Ulusoy et al. [15] show that the use of a 0.75 W Er,Cr:YSGG laser without water cooling improves the enamel's resistance to demineralization. However, the use of a laser affects the long-term durability of enamel due to residual morphological damage on the surface. According to Yilmaz et al. [28], Er,Cr:YSGG laser treatment alone could serve as an alternative method of remineralization, possibly due to modification of the hydroxyapatite structure. Asl-Aminabadi et al. [33] investigated the combination of a Nd:YAG laser and CPP-ACP cream, which also proved successful. However, the use of the Er,Cr:YSGG laser, as stated by Almaz et al. [29], should be approached with more caution because of the occurrence of adverse morphological and spectral changes on the surface of lased teeth. As cavity preparation in deciduous teeth using laser power parameters of 10 Hz and either 200 or 300 mJ is a safe and efficient method for removing tooth structure, the use of 10 Hz and 400 mJ for cavity preparation causes dentin cracking as reported by Zhang et al. [26] (see Table 3).

Table 3. Detailed characteristics of studies.

Reference Number	Laser Type	Investigation	Surface Characterization
Öznurhan [27]	Er,Cr:YSGG 2780 nm, 140–200 µs, 20 Hz	10 human teeth hybrid layer thickness and the amount of silver ions	(dentin) Irregular surface Decrease in collagen content due to ablation
Duruk [2]	Er:YAG 200 mJ, 2 Hz	60 human teeth effect on dentin morphology	(dentin) Closed dentinal tubules Rough surface Ablation craters
Neto [32]	Nd:YAG 100 mJ, 5 Hz, 0.5 W	186 human teeth effect on enamel morphology	(enamel) Smoother surface after using the laser and fluorine than after the laser alone No cracking, melting, or glazing
Flury [16]	Er:YAG 200 mJ, 25 Hz, 5 W; 100 mJ, 35 Hz, 3.5 W; 400 mJ/20 Hz, 8 W; 100 mJ, 35 Hz, 3.5 W; 50 mJ, 35 Hz, 1.75 W.	18 human teeth (cut into dentin samples) effect on dentin morphology	(dentin) Irregular and flaky surface, open tubules, no smear layer Greater ablation in the intertubular dentin than in the peritubular dentin No thermal damage, carbonization, or cracks
Ulusoy [15]	Er,Cr:YSGG 20 Hz + 0.25 W, 4.42 J/cm ^{2} (L1 and L4), 0.50 W, 8.84 J/cm ^{2} (L2 and L5), 0.75 W, 13.26 J/cm ^{2} (L3 and L6)	225 human teeth resistance of enamel to demineralization	(enamel) In the control group, an image of a honeycomb In the fluoride group, an image of a honeycomb with a cloudy surface In places of contact with the laser beam, there are craters with exposed enamel prisms, separated from the normal enamel by a sharp edge. Increasing power = enlarging craters and creating cracks In the group with water cooling, more extensive craters and protruding edges Craters deeper in primary teeth than in permanent teeth

Table 3. *Cont.*

Reference Number	Laser Type	Investigation	Surface Characterization
Wang [17]	Er:YAG 10 Hz, 2940 nm + (50 mJ, 100 mJ, 150 mJ, 200 mJ, 250 mJ, and 300 mJ) 100 mJ, 5 Hz + (10 Hz, 15 Hz, 20 Hz, 25 Hz, and 30 Hz)	80 human teeth effect on dentin morphology, shear bond strength of composite resin to dentin	(dentin) Same energy level, different frequency: 5–15 Hz protrusion of peritubular dentin, ichthyosis appearance, lamellar, irregular surface, open dentinal tubules 15 Hz single cracks 20 Hz ichthyosis appearance, lamellar surface, open channels, deeper cracks 25 Hz larger cracks, blurred border between channels, collapsed structure 30 Hz disorganization of collagen fibers, carbonization Fixed frequency, different energy: 50 mJ open dentinal tubules, irregular surface, no smear layer, protrusion of peritubular dentin 100–200 mJ open dentinal tubules, irregular surface, no smear layer 150 mJ single cracks 200 mJ clear, deep cracks 250 mJ smooth surface, blurred boundaries between channels, larger cracks, collapsed structure 300 mJ collapsed structure, disorganization of collagen fibers, signs of carbonization
Yilmaz [28]	Er,Cr:YSGG 0.5 W, 20 Hz, 25 mJ, 8.84 J/cm^2, 60 µs, 600 µm	89 human teeth enamel remineralization	(enamel) Rough irregular surface, cracks and craters, melted enamel
Almaz [29]	Er,Cr:YSGG I: 0.25 W, 20 Hz, II: 0.50 W, 20 Hz, III: 0.75 W, 20 Hz.	60 human teeth Thermal effects on the pulp	(enamel) Irregular surface, numerous conical craters, ablation areas The depth and number of craters increase as the laser power increases
Asl-Aminabadi [33]	Nd:YAG 200 µm, 15 s, 100 mJ, 125 J/cm^2, 10 Hz, 1 W	80 human teeth enamel remineralization	(enamel) In the laser only group, melting of the enamel, irregular, wavy surface with no continuity, numerous cracks and pits No visible enamel prisms In the fluorine laser group, the surface is smoother and there are fewer cracks
Kahvecioglu [18]	Er:YAG Group I: 0.40 W, 2 Hz, and 200 mJ Group II: 0.60 W, 3 Hz, and 200 mJ Group III: 2 W, 10 Hz, and 200 mJ Group IV: 0.50 W, 2 Hz, and 250 mJ Group V: 0.75 W, 3 Hz, and 250 mJ Group VI: 2.5 W, 10 Hz, and 250 mJ Group VII: 0.60 W, 2 Hz, and 300 mJ Group VIII: 0.90 W, 3 Hz, and 300 mJ Group IX: 3 W, 10 Hz, and 300 mJ	45 human teeth effect on enamel morphology	(enamel) Appearance of a lava stream, more irregular surface at 250 mJ than 200 mJ Cracks, no signs of enamel degradation
Teutle-Coyotecatl [19]	Er:YAG 100, 7 Hz, 400 µs	54 human teeth effect on bacterial adhesion, effect on enamel morphology and bacterial adhesion	(enamel) Rough, scaly surface with clearly defined areas of smooth molten enamel No visible enamel prisms
Guler [20]	Er:YAG 3.5 W, 175 mJ, 20 Hz	36 human teeth effect on surface roughness, effect on dentin morphology	(dentin) Rough, crystalline surface
Öznurhan [30]	Er,Cr:YSGG 3.5 W, 20 Hz	20 human teeth hybrid layer thickness	(dentin) Wavy surface, few cracks, exposed dentinal tubules, no smear layer

Table 3. *Cont.*

Reference Number	Laser Type	Investigation	Surface Characterization
Bahrololoomi [21]	Er:YAG 200 mJ, 10 Hz	48 human teeth effect on dentin morphology, shear bond strength of composite resin to dentin	(dentin) Irregular, flaky surface, slight smear layer When additionally using NaOCl 5.25%, the surface is smoother, there are more open dentinal tubules, and there is no smear layer
Al-Batayneh [22]	Er:YAG 200 mJ, 10 Hz	80 human teeth (40 primary and 40 permanent) thermal effects on the pulp	(enamel) Visible crater-like cavities with smooth edges and a rough bottom (dentine) No smear layer, open dentinal tubules
Memarpour [23]	Er:YAG 20 mJ, 10 Hz, 1.20 W	120 human teeth shear bond strength of composite resin to dentin	(enamel) Irregular surface without smear layer. (dentine) Irregular surface, no smear layer, open dentinal tubules, no visible surface damage
Banda [34]	Nd:YAG The laser parameters were not described	10 human Teeth effect on microhardness	(enamel) In the laser-only group, there is an irregular, rough, wrinkled surface with numerous cavitations and craters In the laser + fluorine group, a homogeneous surface with small porosities and no cracks In the fluorine + laser group, a porous surface with numerous cracks
Monghini [24]	Er:YAG 60 mJ/2 Hz (G2), 80 mJ/2 Hz (G3), 100 mJ/2 Hz (G4)	21 human teeth shear bond strength of composite resin to dentin	(dentin) Uneven, peeling surface, craters and grooves present, and areas where laser radiation did not reach
Wanderley [25]	Er:YAG 60 mJ/2 Hz (G2), 80 mJ/2 Hz (G3), and 100 mJ/2 Hz (G4)	48 human teeth shear bond strength of composite resin to dentin	(enamel) With parameters of 60 mJ/2 Hz, an uneven surface, without a specific etching pattern At 80 mJ/2 Hz, irregular surface, visible cracks, and small melt areas; no specific etching pattern With parameters of 100 mJ/2 Hz, anphractic surface with numerous gaps, without a specific etching pattern
Zhang [26]	Er:YAG 10 Hz/200 mJ, 10 Hz/300 mJ and 10 Hz/400 mJ	8 human teeth effect on dentin morphology	(dentine) No smear layer in 3 cases. Scaly, uneven surface, open dentinal tubules Cracks and melting present only at parameters 400 mJ/10 Hz
Kohara [13]	Er:YAG 300 mJ, 4 H	30 human teeth microleakage at cavities	(dentine) No smear layer, exposed dentinal tubules, micro irregularities, greater ablation of intertubular than peritubular dentin
Arslan [31]	Er,Cr:YSGG 940 nm, 20-Hz; 2780 nm, 20-Hz,	40 human teeth microleakage at cavities	(enamel) Visible cracks on the surface
Guglielmi [35]	Nd:YAG 064 nm, 100 µs, 100 mJ, 15 Hz,1.5 W	39 human teeth effect on dentin morphology	(dentine) Melted surface with areas of recrystallization, dentinal tubule orifices closed with molten material
Bolukbasi [36]	Nd:YAG 2 W, 20 Hz power/cm ^{2}, 100 mJ	Human teeth divided into 240 specimens shear bond strength of composite resin to dentin	(dentin) Smear layer completely removed, dentinal tubules partially open

3.5. Quality Assessment (QA)

The summary of the quality assessment conducted on 24 articles is presented in Table 2. The assessment categorized 11 articles with a moderate risk of bias and 13 with a low risk of bias. None of the analyzed publications were classified as having a high risk of bias (see Table 4).

Table 4. Quality assessment table.

Reference Publications/Criteria	Group Size of min. 10 Samples	Control Group	Sample Size Calculation	Detailed Laser Parameters (Power, Frequency, Wavelength, Spot Size, etc.)	Irradiation Protocol (Distance, Time, Passages)	Detailed Description of Efficacy of the Treatment	Total Points	Risk of Bias
Öznurhan et al. [27]	0	0	0	1	1	1	3	Moderate
Duruk et al. [2]	1	0	0	1	1	1	4	Moderate
Neto et al. [32]	0	1	0	1	1	1	4	Moderate
Flury et al. [16]	0	1	0	1	1	1	4	Moderate
Ulusoy et al. [15]	1	1	0	1	1	1	5	Low
Wang et al. [17]	1	1	1	1	1	1	6	Low
Yilmaz et al. [28]	1	1	1	1	0	1	5	Low
Almaz et al. [29]	1	1	1	1	1	1	6	Low
Asl-Aminabadi et al. [33]	1	1	1	1	1	1	6	Low
Kahvecioglu et al. [18]	0	1	1	1	1	1	5	Low
Teutle-Coyotecatl et al. [19]	1	1	0	1	1	1	5	Low
Guler et al. [20]	1	1	0	1	1	1	5	Low
Öznurhan et al. [30]	1	0	0	1	0	1	3	Moderate
Bahrololoomi et al. [21]	1	0	0	1	0	1	3	Moderate
Al-Batayneh et al. [22]	1	1	0	1	1	1	5	Low
Memarpour et al. [23]	1	0	0	1	1	1	4	Moderate
Banda et al. [34]	1	1	0	0	0	1	3	Moderate
Monghini et al. [24]	1	1	0	1	1	1	5	Low
Wanderley et al. [25]	1	1	0	1	1	1	5	Low
Zhang et al. [26]	0	1	0	1	0	1	3	Moderate
Kohara et al. [13]	1	1	0	1	0	1	4	Moderate
Arslan et al. [31]	1	1	0	1	0	1	4	Moderate
Guglielmi et al. [35]	1	1	0	1	1	1	5	Low
Bolukbasi et al. [36]	1	1	1	1	1	1	6	Low

4. Discussion

Based on the evidence found in the articles analyzed, the null hypothesis of this systematic review was largely confirmed. The majority of the reviewed articles state that the use of different laser systems does not result in a discernible difference in the surface changes of primary teeth when observed by scanning electron microscopy (SEM) imaging. However, as mentioned above, there are still some discrepancies in study results and this topic requires further research. Caries prevalence in young children remains a persistent challenge in dental health [37]. Deciduous teeth possess distinctive characteristics, such as a more prominent prismless layer [3,4] and lower mineral content coupled with higher organic content [5–7], rendering them inherently more susceptible to caries development compared to permanent teeth. Pulpal involvement tends to manifest more rapidly in deciduous teeth due to their proportionately larger pulp chambers and superficial location [38]. It is imperative to note that the pulp of primary teeth exhibits heightened susceptibility to overheating during laser treatment compared to adult pulp [39,40]. As posited by Al-Batayneh et al. [22], the superior ablation efficiency of lasers in enamel and dentin makes them more effective than traditional burrs for carious tissue removal in deciduous teeth.

Nevertheless, a cautious approach is warranted due to the elevated thermal stress experienced by the dental pulp [16,22]. To prevent overheating, Neto et al. [32] recommend the use of laser systems characterized by a short pulse length set at low power density.

Due to the reduced mineralization, bacterial acids have a swifter impact on deciduous tissue. Thus, implementing robust remineralization strategies becomes imperative to counteract the rapid onset of caries in children [40,41]. Noteworthy studies by Neto et al. [32] and Ulusoy et al. [15] substantiated that laser treatment enhances enamel resistance through the reduction of carbonate and hydroxyl groups and the decomposition of the organic matrix. Furthermore, heightened energy intensity leads to a lower mass percentage of carbon, rendering the enamel less soluble and more resilient to caries, as empirically demonstrated by Ulusoy et al. [15], who found that the enamel becomes less soluble and more resistant to caries. Laser irradiation exhibits the potential to amplify the efficacy of fluoride varnish, APF [32] or CPP-ACP [33], improving its interaction with the enamel and increasing the retention of fluoride for a longer period of time. Neto et al. [32] further posited that Nd:YAG laser irradiation alone induces alterations in the chemical composition and microhardness of the enamel surface, without inducing significant morphological changes, effectively impeding the demineralization of deciduous teeth enamel.

There are some discrepancies between authors considering obstruction of dentinal tubules. Duruk et al. [2] reported closed dentinal tubules and concluded that it was due to the ablation effect of the Er:YAG laser. The Er:YAG laser was set at 200 mJ/2 Hz with water cooling of 25 mL/min at a 12-mm distance. Bahrololoomi et al. [21] also observed a smear layer and closed dentinal tubules after usage of the Er:YAG laser set at 200 mJ/10 Hz with water cooling of 7 mL/min from a 17-mm distance, but proved that it can be removed by 5.25% NaOCl. Monghini et al. [24] reported a smear layer and partial obstruction of dentinal tubules at settings of 60 mJ/2 Hz and 80 mJ/2 Hz, yet not at settings of 100 mJ/2 Hz, all lased with the Er:YAG laser within a distance of 17 mm, with water mist at 5 mL/min. Kohara et al. [13] also observed almost no smear layer and mostly patent dentinal tubules after use of 300 mJ energy density with a repetition rate of 4 Hz with water at 1 mL/min. Guglielmi et al. [35] reported dentinal tubules closed by laser-melted material after use of the Nd:YAG laser (100 mJ, 15 Hz) but no smear layer and suggested using the Nd:YAG laser in endodontic treatments of deciduous teeth because of its ability to decrease dentin permeability, which leads to better isolation of developing permanent teeth from pathogens. Other authors denied the presence of a smear layer after lasing [42–47]. There is no straightforward correlation between laser settings, amount of water cooling, and presence of a smear layer. This topic requires further research.

To accurately assess the effectiveness of the treatment method, it is necessary to conduct a prolonged observation on a representative group of patients. Long-term follow-ups during clinical trials provide a comprehensive overview of the assessed issue. Ansari et al. [48] evaluated results of diode laser pulpotomy on human primary teeth. Clinical and radiological controls took place after six and twelve months, allowing for a comparison between laser pulpotomy and the formocresol method. The study concluded that there were no significant differences between these two methods. Similarly, the study carried out by Roy et al. [49] showed promising results after a 12-month follow-up period. The systematic review conducted by Smaïl-Faugeron et al. compared the effects of various pulp treatment techniques, yet it did not encompass laser treatment. This technique presents numerous disparities, as observed by other researchers, thus hindering a comparison [50].

For cavity restoration to be successful, it has to be durable and resistant to the influence of surrounding environments [51,52]. The hybrid layer is a variable on which the longevity of composite fillings strongly depends [53,54]. It decreases microleakage and prevents occurrence of secondary caries [27,55]. Öznurhan et al. [27] stated that cavities prepared with the Er,Cr:YSGG laser and then acid etched present better results with respect to microleakage than those prepared with a traditional drill. But the hybrid layer thickness was reported to be thinner, probably due to ablation exerted by the laser system that leads to a decrease in the collagen content. Monghini et al. [24] found that acid etching of dentin still provides the best results in terms of the hybrid layer compared to the Er:YAG laser regardless of the energy level. However, Flury et al. [16] measured tensile strength and came to the conclusion that bond strength achieved after treatment with the Er:YAG laser is similar to that achieved with a diamond burr. Wang et al. [17] tested shear bond strength and came to the conclusion that bonding strength is enhanced after treatment with the Er:YAG laser. A definite majority of researchers agreed that use of a laser promotes better conditions for stronger resin bonding to dental tissues. However, the issue demands further evaluation due to some differences in experiment results.

Laser treatment offers a significant advantage for both children and adults by minimizing pain [56,57]. When treating children, creating a hospitable environment is crucial for a successful appointment [58,59]. In pediatric dentistry, it is important to limit sound and vibration during treatment to avoid generating dental fear in young patients [9,20,60]. Laser treatment is an option worth considering as it does not require direct contact of an appliance with the tooth tissue, ensuring low noise and no vibration. Al-Batayneh et al. [22] noted that laser preparation is faster in primary teeth than that with traditional burrs, making it advantageous when working with children who have short attention spans and tire quickly.

The main limitation of the present review is that it includes the investigation of different types of lasers. The articles included describe the Er:YAG, Er,Cr:YSGG and Nd:YAG lasers, which differ in their mode of operation and results in terms of surface modification after treatment. Another issue would be the variance of the laser settings used and the conditions of the experiments performed. There is also a significant difference between the sample sizes used in the different experiments and their preparation in non-uniform conditions. In the analyzed (24) articles, the smallest present sample size was 8 [26] and the largest 240 teeth [36]. The articles included varied in utilized laser irradiation (type of laser, power, frequency etc.) and water cooling methodologies which complicates the comparison. Nevertheless, the effectiveness of all treatments was confirmed, evaluated, and deliberated upon.

5. Conclusions

On the basis of the articles collected, the authors of this review concluded that laser treatment, used cautiously, could be an alternative to the classic burr treatment of caries in primary teeth. In addition, laser pretreatment of enamel after fluoride application could be another way to prevent demineralization. Overall, the majority of articles stated that laser treatment promotes better bonding conditions and increases shear bond strength. However, further research is needed as there are many discrepancies between the data found and unexplored aspects such as comparing different types of laser between each other or evaluating any morphological changes over a period of more than one year.

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