Reviews

Effectiveness of laser irradiation in preventing enamel demineralization during orthodontic treatment: A systematic review

Skuteczność promieniowania laserowego w zapobieganiu demineralizacji szkliwa podczas leczenia ortodontycznego – systematyczny przegląd piśmiennictwa

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Abstract

The objective of this study was to investigate the in vivo effectiveness of laser in the prevention of enamel demineralization during orthodontic treatment.

A search of electronic databases (PubMed, ScienceDirect, Google Scholar, Scopus, the Cochrane Central Register of Controlled Trials – CENTRAL, OpenGrey, and ProQuest Dissertations and Theses – PQDT Open from ProQuest) was carried out. In vivo studies, randomized and/or controlled clinical trials regarding the use of laser treatment to prevent enamel demineralization during orthodontic treatment were included. The risk of bias of the studies included was assessed independently by 2 authors according to Cochrane guidelines.

Eight articles were identified, comprising a total of 183 patients. Significant differences were observed in enamel demineralization between laser-irradiated and control groups for all laser types: argon laser, CO_2 laser, neodymium-doped yttrium aluminum garnet (Nd:YAG) laser, and Optodan® laser, except for argon laser application for curing bracket adhesives, where no statistically significant differences were noted.

Laser irradiation may be effective in inhibiting demineralization during orthodontic treatment, but there is a need for further randomized, controlled clinical trials, utilizing different laser systems to determine real clinical efficacy of the technique.

Key words: prevention, laser, orthodontics, white spot lesions, demineralization

Słowa kluczowe: zapobieganie, laser, ortodoncja, białe plamy próchnicowe, demineralizacja

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Introduction

Enamel demineralization or white spot lesion (WSL) development during orthodontic treatment with fixed appliances is a common clinical problem in modern orthodontic practice.[1] Fixed attachments may encourage prolonged plaque accumulation, particularly in patients with poor oral hygiene, compliancy or disability.[2] In addition, a prolonged period of fixed orthodontic treatment increases the risk of WSL formation.[3]

The prevalence of WSLs in patients undergoing orthodontic treatment is about 68.4%, so professional preventive procedures are recommended for fixed orthodontic treatment patients.[3] The responsibility of the orthodontist is to minimize decalcification through education and motivation of the patient to maintain good oral hygiene.[4] Topical fluoride (high-fluoride toothpaste, fluoride mouthwashes, gels and varnishes) is effective in caries prevention and management of WSLs during and after orthodontic treatment.[5]

There is evidence in the literature that laser irradiation modifies the enamel structure, making it more resistant to acid dissolution,[6] so laser application may serve as a preventive measure for WSL formation for orthodontic patients without relying on patient compliancy.

Several types of laser beams have been used to increase enamel resistance to decalcification during orthodontic treatment. These include CO_2, neodymium-doped yttrium aluminum garnet (Nd:YAG), erbium-doped yttrium aluminum garnet (Er:YAG), erbium, chromium: yattrium-scandium-gallium-garnet (Er, Cr:YSGG), diode, and argon lasers.[7,8]

The effectiveness of different lasers in decreasing the susceptibility of the enamel surface to caries have been investigated mostly by in vitro studies and a handful of in vivo studies,[8,9] but the clinical evidence about laser effectiveness is still unclear. There is only 1 published systematic review investigating the effect of lasers in preventing demineralization during orthodontic treatment; however, this study did not involve all types of laser beams that could be applied for this purpose.[10] Equally, there are no reports about the effective and safe laser parameters for clinical use in managing WSL formation.

The aim of this systematic review is to investigate the in vivo effectiveness of different types of laser in preventing enamel demineralization during orthodontic treatment. A secondary aim is to evaluate, using published reports, the effective and safe laser settings that can be used to manage demineralization during orthodontic treatment.

Material and methods

Protocol and registration

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[11]

Review questions:

1. Does laser irradiation significantly increase enamel resistance to demineralization during orthodontic treatment?
2. What are the most effective and safest lasers for the prevention of demineralization related to orthodontic treatment?

Table 1. Review questions – PICO study design

	Review questions – PICO study design
Population	Eligibility criteria: – healthy patients with permanent teeth, receiving orthodontic treatment with fixed orthodontic appliances (no predetermined restrictions on initial malocclusion or indications for treatment); – patients of any age; – patients of both genders; – patients of any ethnic group. Exclusion criteria: – syndromic patients; – patients with any systemic disease; – patients with teeth with enamel imperfections or restorations
Intervention	Application of different laser beams on enamel during orthodontic treatment.
Comparison	Formation of WSLs or enamel demineralization – comparison between laser-irradiated enamel and non-manipulated enamel, or with other preventive procedures applied.
Outcome	Primary outcome: – formation or no formation of WSLs, assessed by clinical diagnosis or on digital images; – degree of decalcification; – changes in the enamel structure after laser application.
Study design	Eligibility criteria: – in vivo studies (human studies); – RCTs; – CCTs; – no predetermined restrictions on language, year of publication or publication status. Exclusion criteria: – case reports or case series; – editorials, personal opinions, reviews, and technique description articles, without a reported sample; – in vitro studies and animal studies.

PICO – population, intervention, comparison, and outcome study design; WSL – white spot lesion; RCT – randomized controlled trial; CCT – controlled clinical trial.

These review questions were developed according to the population, intervention, comparison, and outcome (PICO) study design (Table 1).

Types of publications

This review included all publications, regardless of language, about the clinical application of different laser types to prevent WSLs or enamel demineralization during fixed orthodontic treatment. Personal opinions, editorials, literature reviews, and abstracts were excluded.

Eligibility criteria of the population were:
- healthy patients with permanent teeth, receiving orthodontic treatment with fixed orthodontic appliances;
- patients of any age;
- patients of both genders;
- patients of any ethnic groups.

Exclusion criteria of the population were:
- syndromic patients;
- patients with any systemic disease;
- patients with teeth with enamel imperfections or restorations.

Information sources

The search strategy incorporated searching electronic databases, supplemented by hand searching. The electronic search was performed in PubMed (National Library of Medicine – NLM, National Center for Biotechnology Information – NCBI), ScienceDirect, Google Scholar, Scopus, the Cochrane Central Register of Controlled Trials (CENTRAL), OpenGrey (to identify the grey literature), and ProQuest Dissertations and Theses (PQDT Open) from ProQuest (to identify dissertations and theses). The references of each relevant study were screened to discover additional relevant publications and to improve the sensitivity of the search. ClinicalTrials.gov and the World Health Organization International Clinical Trials Registry Platform Search Portal (ICTRP) were also screened to evaluate any unpublished studies or current accomplished research work.

Hand searching was carried out in the following journals: "American Journal of Orthodontics and Dentofacial Orthopedics"; "Australasian Orthodontic Journal"; "Caries Research"; "European Journal of Orthodontics"; "Journal of Biomedical Optics"; "Lasers in Medical Science"; "Lasers in Surgery and Medicine"; "Laser Therapy"; "Orthodontics and Craniofacial Research"; "Photomedicine and Laser Surgery"; "Seminars in Orthodontics"; "Angle Orthodontist"; "Journal of Orthodontics"; and "Korean Journal of Orthodontics".

Search

PubMed, Scopus, ScienceDirect, Google Scholar, and Cochrane databases were explored through advanced searches. The search was conducted in June 2017, using the following keywords: (laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances). The full electronic search strategy is presented in Supplementary Material 1.

Study selection

The obtained articles were independently subjected to clear inclusion and exclusion criteria by 2 authors (TRR and GM).

Inclusion criteria for the studies were:
- in vivo studies (human studies);
- randomized controlled trials (RCTs);
- controlled clinical trials (CCTs).

Exclusion criteria for the studies were:
- case reports or case series;
- editorials, personal opinions, reviews, and technique description articles, without a reported sample;
- in vitro studies and animal studies.

Sequential search strategy

Firstly, all article titles were screened and the irrelevant articles, reviews, case reports, and in vitro studies were excluded. Then, abstracts of the remaining articles were screened to eliminate studies based on data obtained from abstracts. Finally, the full text of the remaining articles was screened to confirm the acceptability of the articles depending on the inclusion and exclusion criteria.

The authors compared their decisions and resolved differences through discussion, consulting a third author (OH) when consensus could not be reached. The 3rd author was an experienced senior reviewer.

Data extraction

The data was extracted from the studies according to the aims of the systematic review by the same 2 authors (TRR and GM) independently and were arranged in the following fields: general information (name of author and year of publication); study characteristics (study design and treatment comparison); sample description (size, age and sex); laser application (type of laser beam, laser parameters and details of irradiation protocol); and outcomes (primary outcomes, methods of primary outcome measurement, and statistical significance of the reported differences between treated and control groups).

Supplementary Material 1. Literature databases searched with a search strategy (last search on June 30, 2017)

Database	Site	Search strategy	Search builder	Limits	Items	Items involved after excluding irrelevant articles
PubMed	http://www.ncbi.nlm.nih.gov/pubmed/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	all fields	–	42,045	106
CENTRAL (Cochrane Library)	http:// www.cochranelibrary.com/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	title, abstract, keywords	trials	8,650	27
ScienceDirect	https://www.sciencedirect.com/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	title, abstract, keywords	–	7	6
Google Scholar	https://scholar.google.com/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	–	–	1,520	53
Scopus	http://www.scopus.com/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	title, abstract, keywords	–	118	22
OpenGrey	http://www.opengrey.eu/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	–	orthodontics	416	5
PQDT Open (from ProQuest)	http://pqdtopen.proquest.com/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	–	–	0	0
ClinicalTrials.gov	https://clinicaltrials.gov/	Condition or disease: (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) Other terms: (laser therapy) OR (laser irradiation) OR (laser application) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	all	–	8	1
WHO ICTRP	http://apps.who.int/trialsearch/	(laser therapy) OR (laser irradiation) OR (laser application) AND (enamel caries prevention) OR (enamel resistance) OR (enamel decalcification) OR (enamel demineralization) OR (white spot lesions WSLs) OR (enamel dissolution) OR (enamel microhardness) AND (orthodontics) OR (orthodontic treatment) OR (orthodontic brackets) OR (fixed appliances)	all	–	776	2
Overall					53,540	222*

* There were 53,540 items identified from electronic databases. 473 items were added through hand searching and references screening. After excluding irrelevant articles, there were 222 items involved from electronic search and 150 items from hand searching and references screening. Then, after filtering for duplication, there were 304 items left (155 items from electronic databases and 149 items from hand searching and references screening).

Assessment of methodological quality

The risk of bias of the included trials was also assessed independently by the same 2 authors (TRR and GM), using the recommended approach for assessing the risk of bias in studies included in Cochrane reviews.[12] The studies were evaluated in the following fields as low, high or unclear risk of bias: sequence generation (selection bias); allocation concealment (selection bias); blinding of participants and personnel (performance bias); blinding of outcome assessors (detection bias); incomplete outcome data addressed (attrition bias); selective outcome reporting (reporting bias); and other bias types. The overall risk of bias of the included trials was assessed according to the following criteria: low risk of bias – if all fields were assessed as low risk of bias; unclear risk of bias – if at least 1 field was assessed as unclear risk of bias; and high risk of bias – if at least 1 field was assessed as high risk of bias.

Synthesis of results and statistical analysis

Relevant data related to the previously stated variables was collected and organized into tables. No meta-analyses could be performed due to the heterogeneity of study designs, treatment protocols and outcomes.

Results

Study selection

Article review and data extraction was performed according to the PRISMA flow diagram. The initial search identified a total of 54,013 references. Following the screening of the article titles, 304 potentially relevant articles were identified. Independent screening of the abstracts resulted in the selection of 23 publications and 1 protocol (for ongoing study) for possible inclusion. The inclusion and exclusion criteria were applied to the 23 full-text articles. Finally, 8 articles that met the predefined criteria were included in the current systematic review. The PRISMA flow chart (Fig. 1) illustrates the search methodology and results.

Exclusion of studies

The reasons for excluding studies after full-text assessment were as follows: use of non-human enamel (n = 1), in vitro studies (n = 4), the clinical aspect not applied through orthodontic treatment (n = 7), studies on primary teeth (n = 1), full text non-available (n = 2). The excluded studies, together with the reasons of excluding, are outlined in Supplementary Material 2.

Quality assessment

The quality assessment of the included studies revealed unclear risk of bias (for 1 or more key domains) in the 8 studies included. Blinding of participants and blinding during outcome assessment were the most problematic fields (unclear risk of bias in 87.5% and 75% of studies, respectively). The overall risk of bias for the included studies is summarized in Fig. 2 and 3.

Study characteristics

The studies were compared regarding the sample size, study design, type and parameters of the laser applied, and the main outcomes. The 8 articles were published between 2000 and 2015. They involved 183 patients, and the main inclusion criterion was healthy patients in need of orthodontic treatment without caries, demineralization or restorations on the facial surfaces of teeth, except for the trial by Harazaki et al., which included orthodontic patients with early demineralization.[13] Intervention in all trials was the application of different laser types; 4 studies applied an argon laser, 2 studies applied a CO_2 laser, 1 study applied an Nd:YAG laser, and 1 study applied an Optodan® laser. The characteristics of the 8 studies are summarized in Table 2.

Results of individual studies

Four clinical studies applied an argon laser[14–17] and 3 of them reported a significant reduction in the lesion depth, measured on microphotographs of the polarized light microscopy, for the argon laser-irradiated groups of teeth compared to the control groups ($p \leq 0.05$).[14–16] One study did not find a significant effect of argon laser curing on enamel WSL formation, evaluated on the basis of photographs, in the laser group compared to the control group ($p \geq 0.05$).[17]

Two studies applied a CO_2 laser to enamel around orthodontic brackets and reported that CO_2 laser irradiation produced marked demineralization inhibition in short and medium follow-up terms, as it led to significantly higher enamel microhardness compared to the control non-irradiated enamel ($p \leq 0.04$).[18,19]

One clinical study applied an Nd:YAG laser to enamel with WSLs and showed that it was effective in inhibiting the development of dental caries, as the increase of the WSL area was significantly lower compared to the control group ($p \leq 0.05$).[13]

One clinical trial used an Optodan low-intensity laser around orthodontic brackets and reported that the growth index in dental and surface caries intensity was significantly lower in the laser therapy group than in the control group ($p \leq 0.001$).[20] The results of the studies included are summarized in Table 3.

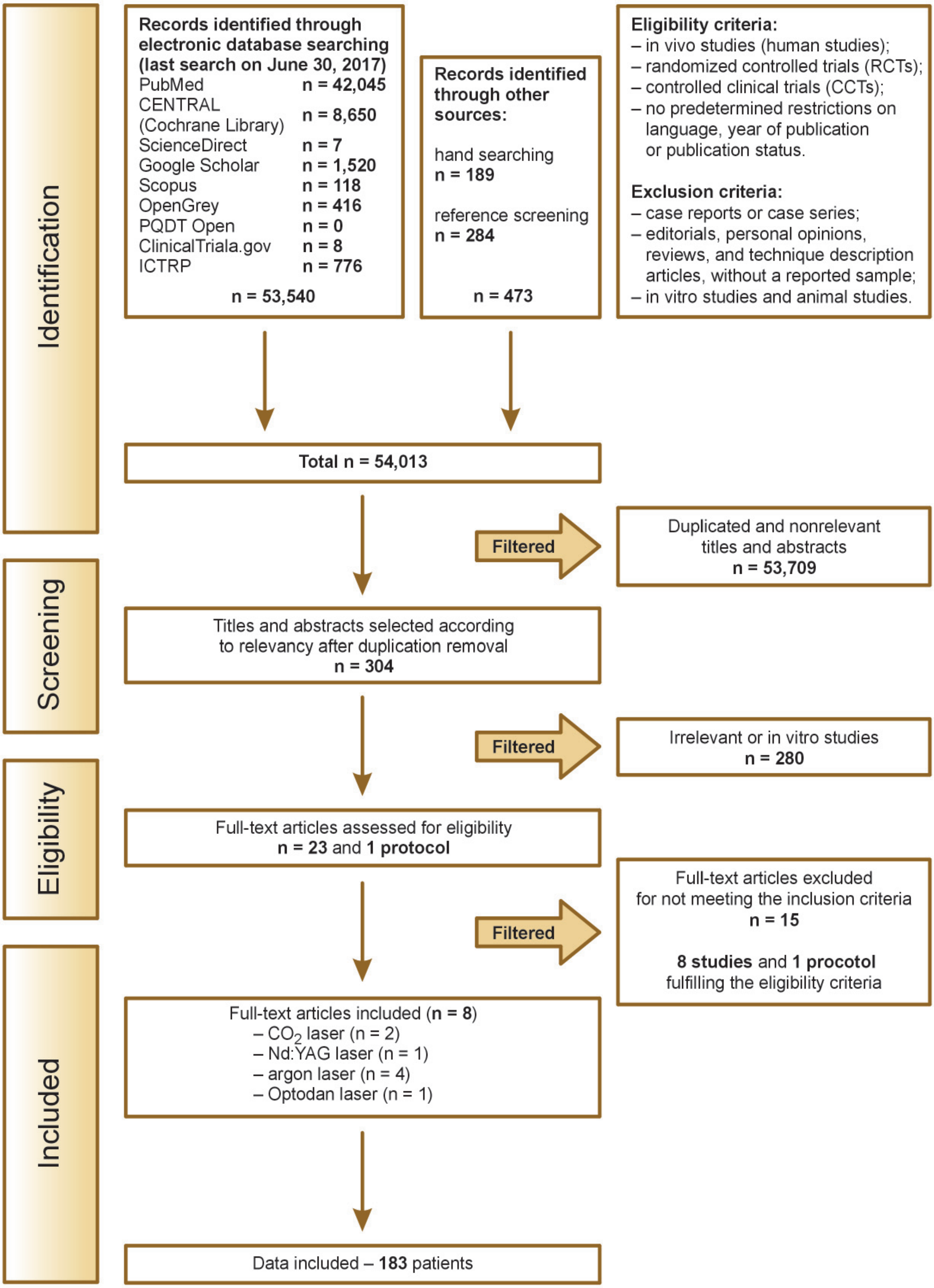

Fig. 1. PRISMA flow diagram illustrating the literature search protocol
PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Supplementary Material 2. Studies excluded after full text reading with the reasons of excluding

Study	Reason of excluding
Souza-Gabriel AE, Turssi CP, Colucci V, Tenuta LM, Serra MC, Corona SA. In situ study of the anticariogenic potential of fluoride varnish combined with CO_2 laser on enamel. *Arch Oral Biol.* 2015;60(6):804–810.	non-human enamel
Stangler LP, Romano FL, Shirozaki MU, et al. Microhardness of enamel adjacent to orthodontic brackets after CO_2 laser irradiation and fluoride application. *Braz Dent J.* 2013;24(5):508–512.	in vitro study
Seino PY, Freitas PM, Marques MM, de Souza Almeida FC, Botta SB, Moreira MS. Influence of CO_2 (10.6 µm) and Nd:YAG laser irradiation on the prevention of enamel caries around orthodontic brackets. *Lasers Med Sci.* 2015;30(2):611–616.	in vitro study
Kantorowitz Z, Featherstone JD, Fried D. Caries prevention by CO_2 laser treatment: Dependency on the number of pulses used. *J Am Dent Assoc.* 1998;129(5):585–591.	in vitro study
Lara-Carrilloa E, Doroteo-Chimalb C, Lopez-Gonzaleza S, et al. Remineralization effect of low-level laser and amorphous sodium–calcium–phosphosilicate paste in teeth with fixed orthodontic appliances. *Tanta Dental Journal.* 2016;13(1):55–62.	in vitro study
Zezell DM, Boari HGD, Ana PA, Eduardo Cde P, Powell GL. Nd:YAG laser in caries prevention: A clinical trial. *Lasers Surg Med.* 2009;41(1):31–35.	clinical study, but not applied during orthodontic treatment
Correa-Afonso AM, Pécora JD, Palma-Dibb RG. Influence of laser irradiation on pits and fissures: An in situ study. *Photomed Laser Surg.* 2013;31(2):82–89.	clinical study, but not applied during orthodontic treatment
Nammour S, Demortier G, Florio P, et al. Increase of enamel fluoride retention by low fluence argon laser in vivo. *Lasers Surg Med.* 2003;33(4):260–263.	clinical study, but not applied during orthodontic treatment
Nammour S, Rocca JP, Pireaux JJ, Powell G, Morciaux Y, Demortir G. Increase of enamel fluoride retention by low fluence argon laser beam: A 6-month follow-up study in vivo. *Lasers Surg Med.* 2005;36(3):220–224.	clinical study, but not applied during orthodontic treatment
Apel C, Birker L, Meister J, Weiss C, Gutknecht N. The caries-preventive potential of subablative Er:YAG and Er:YSGG laser radiation in an intraoral model: A pilot study. *Photomed Laser Surg.* 2004;22(4):312–317.	clinical study, but not applied during orthodontic treatment
Korytnicki D, Mayer MP, Daronch M, Singer Jda M, Grande RH. Effects of Nd:YAG laser on enamel microhardness and dental plaque composition: An in situ study. *Photomed Laser Surg.* 2006;24(1):59–63.	clinical study, but not applied during orthodontic treatment
Rechmann P, Charland DA, Rechmann BM, Le CQ, Featherstone JD. In vivo occlusal caries prevention by pulsed CO_2 laser and fluoride varnish treatment: A clinical pilot study. *Lasers Surg Med.* 2013;45(5):302–310.	clinical study, but not applied during orthodontic treatment
Raucci-Neto W, de Castro-Raucci LM, Lepri CP, Faraoni-Romano JJ, Gomes da Silva JM, Palma-Dibb RG. Nd:YAG laser in occlusal caries prevention of primary teeth: A randomized clinical trial. *Lasers Med Sci.* 2015;30(2):761–768.	study on primary teeth
Jacobson A. The effect of argon laser irradiation on reducing enamel decalcification during orthodontic treatment: An in vitro and in vivo study. *Am J Orthod Dentofacial Orthop.* 2006;129(1):82.	full text non-available
Rodrigues L, Parisotto T, Steiner-Oliveira C, Azevedo L, Tabchoury C. Effect of CO_2 laser and fluoride dentifrice on demineralization around orthodontic brackets: An in situ study. *Lasers Surg Med.* 2014;46:57.	full text non-available

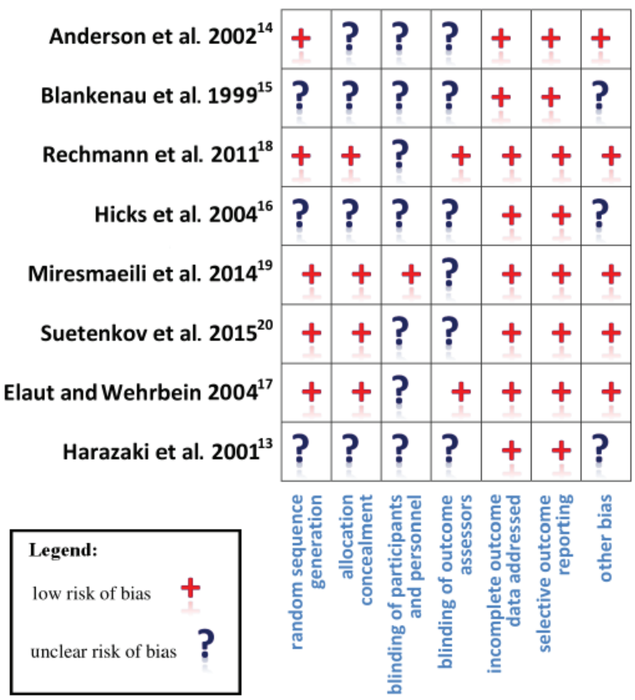

Fig. 2. Summary of the risk of bias for the studies included

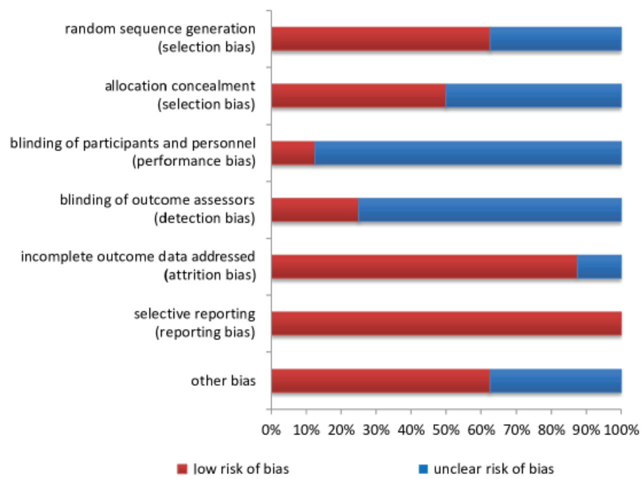

Fig. 3. Overall risk of bias score for each field

Table 2. Characteristics of the trials included

Study	Methods		Participants	Intervention			Follow-up time	Primary outcomes	Methods of measurement of primary outcomes
	study design	treatment comparison		type of laser beam	laser parameters	details of irradiation protocol			
Anderson et al. 2002[14]	RCT	amount of decalcification in the control group and the argon laser-irradiated groups of teeth (non-pumiced-non-etched group, pumiced group and etched group)	9 patients scheduled for orthodontic treatment with the extraction of 4 premolars; 36 premolars allocated in 4 groups (inclusion criteria: teeth without enamel defects or decalcification)	argon laser	– beam: 325 mW; – time: 60 s; – fluence (energy density): 100 J/cm^2; – beam diameter: 5 mm; irradiated through a wand handled at a distance of about 3 mm from the facial surface of the tooth	in 3 lased groups, the laser was applied alone or after pumicing or after pumicing and etching; then modified orthodontic bands with pockets to plaque accumulation were fitted on the premolars	5 weeks; then the teeth were extracted	lesion depth measurement [μm]; lesion area measurement [μm^2]	polarized light microscopy – digital microscope images were examined and measured
Blankenau et al. 1999[15]	clinical pilot study	demineralization of enamel in the laser-irradiated and control teeth	4 patients needing orthodontic treatment with bilateral premolar extraction; 4 pairs of premolars from each participant (1 experimental and 3 control)	argon laser	– beam: 250 mW; – time:10 s; – fluence: 12 J/cm^2; – beam diameter: 5 mm	after experimental teeth irradiation, modified orthodontic bands were fitted on the lased and control teeth	5 weeks; then the teeth were extracted	lesion depth	polarized light microscopy
Elaut and Wehrbein 2004[17]	RCT (SP)	bracket bonding failure and enamel decalcification in argon laser-cured and conventional light-cured bracket adhesives through orthodontic treatment	45 patients (28 girls and 17 boys), average age: 12 years 11 months, 742 teeth; in each patient, teeth with odd numbers received argon laser curing and teeth with even numbers had conventional light curing of bracket adhesives; the maxillary anterior teeth (212) were evaluated for decalcification (inclusion criteria: patients with fully erupted and restoration-free contralateral pairs of teeth)	argon laser	– beam: 250 mM (continuous mode) – time: 5 s from the incisal side and 5 s from the gingival side; – fluence: 12 J/cm^2; – beam diameter: 5 mm	thermoformed plastic/aluminium foil was used to cover the control teeth during argon laser curing	14 months for enamel decalcification (after removing brackets from the maxillary anterior teeth), 12 months for plaque accumulation; the bonding failure rate was evaluated for 4–5 weeks after bonding	absence or degree of WSLs on enamel on the facial surfaces of maxillary anterior teeth; plaque accumulation on the maxillary anterior teeth; the bonding failure rate during the study period	enamel decalcification and plaque accumulation were evaluated through comparing digital images before and after the study period by a team of 7 examiners
Harazaki et al. 2001[13]	clinical trial	increase in WSLs in the laser-irradiated and the control patients; enamel changes in the irradiated and non-manipulated parts of enamel of the premolar	in vivo part of the study: 10 patients undergoing orthodontic treatment, with enamel WSLs on their teeth, the other 10 patients were a control group; the focus was on maxillary incisors in vitro part of the study: laser irradiation was applied to 1 extracted premolar	Nd:YAG laser	– pulse width: 0.3 ms; – pulse energy: 0.75 J; – power: 2 × 10 W; – repeated 20 pps; – time: 5 s; – fluence: 40 J/cm^2	in vivo study: the experimental group of 10 patients was administered a black liquid agent, then it was irradiated with laser, and finally the APF gel was applied in vitro study: one part of the extracted premolar was painted with a black liquid, and then irradiated with laser, while the other part of the premolar was used as a control	1 year	increase in the area of WSLs after 1 year in the experimental and control groups; enamel surface changes in the irradiated and control parts of the extracted premolar	WSLs were traced by taking photographs and with tracing paper, and the total WSL area was calculated before laser irradiation and after 1 year; enamel surface changes were observed by SEM
Hicks et al. 2004[16]	clinical pilot study	lesion depth in argon laser irradiated-teeth in the argon and fluoride group and the control (non-treatment) group	5 patients (3 females, 2 males), age: 19–28 years, requiring orthodontic treatment with tooth extraction (14 teeth); the teeth were caries-free on the buccal surfaces	argon laser	– beam: 250 mW; – time: 10 s; – fluence: 12 J/cm^2	the teeth were assigned in 3 groups: argon laser, topical fluoride followed by argon laser irradiation, and no treatment (control), then modified orthodontic bands with plaque retentive slots were placed on the teeth	5 weeks; then the teeth were extracted	lesion depth in the 3 groups	polarised light microscopy
Miresmaeili et al. 2014[19]	RCT (SP)	enamel surface microhardness in the treated and control premolars	16 patients (11 females, 5 males) scheduled for the extraction of at least 2 premolars. (1 first or second premolar treated with laser – 16 teeth, the premolar from the other side in the same patient served as a control – 16 teeth) (inclusion criteria: age <25 years, complete eruption of teeth, no lesions on the enamel surfaces, moderate to good oral hygiene; exclusion criteria: patients with enamel lesions or cracks on the buccal surfaces)	CO_2 laser	– wave length: 10.6 μm; – pulse duration: 3 s; – pulse repetition rate: 5 Hz; – beam diameter: 0.2 mm; – power: 0.7 W	the experimental teeth were irradiated with laser and the control premolars were exposed to non-theraputic light; then orthodontic brackets were attached to both premolars and the T-loop was engaged to the brackets to increase plaque accumulation	at least 2 months after laser irradiation, then the teeth were extracted (1 tooth from each group was extracted after 1 week of laser irradiation for the SEM evaluation)	enamel surface microhardness around orthodontic brackets; enamel surface changes after laser therapy	Vickers diamond microhardness testing machine was used to evaluate enamel surface microhardness; SEM was used to observe enamel surface changes
Rechmann et al. 2011[18]	RCT (PG)	enamel demineralization around orthodontic brackets in the laser-irradiated area and other area in the same tooth as a control	24 patients (13 females, 11 males), average age:14.9 ±2.2 years, randomly assigned to 4-week (average age: 14.6 ±2.3 years) and 12-week (average age: 15.2 ±2.1 years) study arms (inclusion criteria: healthy patients, aged 12–18 years, scheduled to premolar extraction for orthodontic reasons, teeth without caries or restorations on the facial surface; exclusion criteria: systematic diseases, medication affecting oral flora or salivary flow, fluoride treatment in the last 3 months)	CO_2 laser	– wave length: 9.6 μm; – pulse duration: 20 μs; – pulse repetition rate: 20 Hz; – beam diameter: 1,100 μm; – fluence per pulse: 3.3–4.4 J/cm^2; irradiated through a straight laser handpiece	the laser beam was applied on enamel, cervical to the bracket of the premolar on one side of an imaginary line, perpendicular to the bracket slot, while the other side of the line in the same tooth served as a control; each spot of the testing area was irradiated with 20 pulses and laser irradiation was applied only once	4 weeks for one group (12 patients) and 12 weeks for the other group (12 patients); then the teeth were extracted	overall relative mineral loss in the 4-week and 12-week arms in the irradiated and control enamel	cross-sectional microhardness testing
Suetenkov et al. 2015[20]	RCT	dental caries and oral hygiene in the group with traditional preventive measures and the group with laser therapy and traditional preventive measures	60 patients (20 girls, 40 boys), age: 12–13 years, divided into 2 groups (30 patients in each group)	Optodan (low-intensity) laser	– wave length: 0.98–0.85 nm; – power: 0.5–1.0 W; – pulse repetition rate: 2000 Hz; – time: 2 min for each segment	the irradiated area included 2 segments (upper and lower teeth aligments); irradiation was applied after professional oral hygiene measures were taken, and there were 4 courses per year, every 3 months	1 year (after orthodontic treatment completion and removing orthodontic brackets)	oral hygiene and caries intensity before and after orthodontic treatment in both groups	visual examination to determine OHI-S, DMFT index and DMFS index before and after the treatment for both groups

APF – acidulated phosphate fluoride; DMFT – count of Decayed, Missing and Filled Teeth; DMFS – count of Decayed, Missing and Filled tooth Surfaces; Nd: YAG – neodymium-doped yttrium aluminum garnet; OHI-S – simplified oral hygiene index; PG – parallel groups; pps – pulse per second; RCT – randomized controlled trial; SEM – scanning electron microscopy; SP – split-mouth design; WSL – white spot lesion.

Table 2. Characteristics of the trials included

Study	Methods		Participants	Intervention			Follow-up time	Primary outcomes	Methods of measurement of primary outcomes
	study design	treatment comparison		type of laser beam	laser parameters	details of irradiation protocol			
Anderson et al. 2002[14]	RCT	amount of decalcification in the control group and the argon laser-irradiated groups of teeth (non-pumiced-non-etched group, pumiced group and etched group)	9 patients scheduled for orthodontic treatment with the extraction of 4 premolars; 36 premolars allocated in 4 groups (inclusion criteria: teeth without enamel defects or decalcification)	argon laser	– beam: 325 mW; – time: 60 s; – fluence (energy density): 100 J/cm^2; – beam diameter: 5 mm; irradiated through a wand handled at a distance of about 3 mm from the facial surface of the tooth	in 3 lased groups, the laser was applied alone or after pumicing or after pumicing and etching; then modified orthodontic bands with pockets to plaque accumulation were fitted on the premolars	5 weeks; then the teeth were extracted	lesion depth measurement [μm]; lesion area measurement [$μm^2$]	polarized light microscopy – digital microscope images were examined and measured
Blankenau et al. 1999[15]	clinical pilot study	demineralization of enamel in the laser-irradiated and control teeth	4 patients needing orthodontic treatment with bilateral premolar extraction; 4 pairs of premolars from each participant (1 experimental and 3 control)	argon laser	– beam: 250 mW; – time:10 s; – fluence: 12 J/cm^2; – beam diameter: 5 mm	after experimental teeth irradiation, modified orthodontic bands were fitted on the lased and control teeth	5 weeks; then the teeth were extracted	lesion depth	polarized light microscopy
Elaut and Wehrbein 2004[17]	RCT (SP)	bracket bonding failure and enamel decalcification in argon laser-cured and conventional light-cured bracket adhesives through orthodontic treatment	45 patients (28 girls and 17 boys), average age: 12 years 11 months, 742 teeth; in each patient, teeth with odd numbers received argon laser curing and teeth with even numbers had conventional light curing of bracket adhesives; the maxillary anterior teeth (212) were evaluated for decalcification (inclusion criteria: patients with fully erupted and restoration-free contralateral pairs of teeth)	argon laser	– beam: 250 mM (continuous mode) – time: 5 s from the incisal side and 5 s from the gingival side; – fluence: 12 J/cm^2; – beam diameter: 5 mm	thermoformed plastic/aluminium foil was used to cover the control teeth during argon laser curing	14 months for enamel decalcification (after removing brackets from the maxillary anterior teeth), 12 months for plaque accumulation; the bonding failure rate was evaluated for 4–5 weeks after bonding	absence or degree of WSLs on enamel on the facial surfaces of maxillary anterior teeth; plaque accumulation on the maxillary anterior teeth; the bonding failure rate during the study period	enamel decalcification and plaque accumulation were evaluated through comparing digital images before and after the study period by a team of 7 examiners
Harazaki et al. 2001[13]	clinical trial	increase in WSLs in the laser-irradiated and the control patients; enamel changes in the irradiated and non-manipulated parts of enamel of the premolar	in vivo part of the study: 10 patients undergoing orthodontic treatment, with enamel WSLs on their teeth, the other 10 patients were a control group; the focus was on maxillary incisors in vitro part of the study: laser irradiation was applied to 1 extracted premolar	Nd:YAG laser	– pulse width: 0.3 ms; – pulse energy: 0.75 J; – power: 2 × 10 W; – repeated 20 pps; – time: 5 s; – fluence: 40 J/cm^2	in vivo study: the experimental group of 10 patients was administered a black liquid agent, then it was irradiated with laser, and finally the APF gel was applied in vitro study: one part of the extracted premolar was painted with a black liquid, and then irradiated with laser, while the other part of the premolar was used as a control	1 year	increase in the area of WSLs after 1 year in the experimental and control groups; enamel surface changes in the irradiated and control parts of the extracted premolar	WSLs were traced by taking photographs and with tracing paper, and the total WSL area was calculated before laser irradiation and after 1 year; enamel surface changes were observed by SEM
Hicks et al. 2004[16]	clinical pilot study	lesion depth in argon laser irradiated-teeth in the argon and fluoride group and the control (non-treatment) group	5 patients (3 females, 2 males), age: 19–28 years, requiring orthodontic treatment with tooth extraction (14 teeth); the teeth were caries-free on the buccal surfaces	argon laser	– beam: 250 mW; – time: 10 s; – fluence: 12 J/cm^2	the teeth were assigned in 3 groups: argon laser, topical fluoride followed by argon laser irradiation, and no treatment (control), then modified orthodontic bands with plaque retentive slots were placed on the teeth	5 weeks; then the teeth were extracted	lesion depth in the 3 groups	polarised light microscopy
Miresmaeili et al. 2014[19]	RCT (SP)	enamel surface microhardness in the treated and control premolars	16 patients (11 females, 5 males) scheduled for the extraction of at least 2 premolars. (1 first or second premolar treated with laser – 16 teeth, the premolar from the other side in the same patient served as a control – 16 teeth) (inclusion criteria: age <25 years, complete eruption of teeth, no lesions on the enamel surfaces, moderate to good oral hygiene; exclusion criteria: patients with enamel lesions or cracks on the buccal surfaces)	CO_2 laser	– wave length: 10.6 μm; – pulse duration: 3 s; – pulse repetition rate: 5 Hz; – beam diameter: 0.2 mm; – power: 0.7 W	the experimental teeth were irradiated with laser and the control premolars were exposed to non-theraputic light; then orthodontic brackets were attached to both premolars and the T-loop was engaged to the brackets to increase plaque accumulation	at least 2 months after laser irradiation, then the teeth were extracted (1 tooth from each group was extracted after 1 week of laser irradiation for the SEM evaluation)	enamel surface microhardness around orthodontic brackets; enamel surface changes after laser therapy	Vickers diamond microhardness testing machine was used to evaluate enamel surface microhardness; SEM was used to observe enamel surface changes
Rechmann et al. 2011[18]	RCT (PG)	enamel demineralization around orthodontic brackets in the laser-irradiated area and other area in the same tooth as a control	24 patients (13 females, 11 males), average age:14.9 ±2.2 years, randomly assigned to 4-week (average age: 14.6 ±2.3 years) and 12-week (average age: 15.2 ±2.1 years) study arms (inclusion criteria: healthy patients, aged 12–18 years, scheduled to premolar extraction for orthodontic reasons, teeth without caries or restorations on the facial surface; exclusion criteria: systematic diseases, medication affecting oral flora or salivary flow, fluoride treatment in the last 3 months)	CO_2 laser	– wave length: 9.6 μm; – pulse duration: 20 μs; – pulse repetition rate: 20 Hz; – beam diameter: 1,100 μm; – fluence per pulse: 3.3–4.4 J/cm^2; irradiated through a straight laser handpiece	the laser beam was applied on enamel, cervical to the bracket of the premolar on one side of an imaginary line, perpendicular to the bracket slot, while the other side of the line in the same tooth served as a control; each spot of the testing area was irradiated with 20 pulses and laser irradiation was applied only once	4 weeks for one group (12 patients) and 12 weeks for the other group (12 patients); then the teeth were extracted	overall relative mineral loss in the 4-week and 12-week arms in the irradiated and control enamel	cross-sectional microhardness testing
Suetenkov et al. 2015[20]	RCT	dental caries and oral hygiene in the group with traditional preventive measures and the group with laser therapy and traditional preventive measures	60 patients (20 girls, 40 boys), age: 12–13 years, divided into 2 groups (30 patients in each group)	Optodan (low-intensity) laser	– wave length: 0.98–0.85 nm; – power: 0.5–1.0 W; – pulse repetition rate: 2000 Hz; – time: 2 min for each segment	the irradiated area included 2 segments (upper and lower teeth aligments); irradiation was applied after professional oral hygiene measures were taken, and there were 4 courses per year, every 3 months	1 year (after orthodontic treatment completion and removing orthodontic brackets)	oral hygiene and caries intensity before and after orthodontic treatment in both groups	visual examination to determine OHI-S, DMFT index and DMFS index before and after the treatment for both groups

APF – acidulated phosphate fluoride; DMFT – count of Decayed, Missing and Filled Teeth; DMFS – count of Decayed, Missing and Filled tooth Surfaces; Nd: YAG – neodymium-doped yttrium aluminum garnet; OHI-S – simplified oral hygiene index; PG – parallel groups; pps – pulse per second; RCT – randomized controlled trial; SEM – scanning electron microscopy; SP – split-mouth design; WSL – white spot lesion.

Table 3. Summary of the results of the studies included

Study	Sample size of each group	Outcome	Mean	Standard deviation (SD)	p-value	Results
Anderson et al. 2002[14]	36 teeth in 4 groups (9 per group)	lesion depth in PLM	G1 (ctr): 15.69 µm G2 (pumice+laser): 6.45 µm G3 (pumice+etch+laser): 1.71 µm G4 (laser only): 1.34 µm	G1 (ctr): 9.30 G2 (pumice+laser): 8.70 G3 (pumice+etch+laser): 4.80 G4 (laser only): 3.80	<0.05	reduction in lesion depth was significant as compared to G1: G2: 58.9% G3: 89.1% G4: 91.6%
Blankenau et al. 1999[15]	4 patients 4 pairs of teeth (each patient 1 ctr and 1 exp tooth)	lesion depth in PLM	pair 1 – ctr: 17,959 nm/exp: 11,976 nm pair 2 – ctr: 313,622 nm/exp: 213,445 nm pair 3 – ctr: 178,528 nm/exp: 128,218 nm pair 4 – ctr: 154,163 nm/exp: 118,004 nm			decrease in lesion depth in the lased tooth: pair 1: 33% pair 2: 31.9% pair 3: 28.1% pair 4: 23.4%
Elaut and Wehrbein 2004[17]	45 patients 742 teeth 212 teeth evaluated for decalcification (106 with traditional curing + 106 with argon curing)	comparison of the incidence of decalcification before and after the treatment plaque accumulation	ctr group: 85/106 teeth (54%) showed more decalcification at the end of the treatment exp group: 62/106 teeth (58.5%) showed more decalcification plaque accumulation scores: ctr group: 2.34 exp group: 2.39	plaque accumulation scores: ctr group: 0.86 exp group: 9.81	>0.05	differences in decalcification increase were not statistically significant there were no significant differences in the plaque accumulation scores between the 2 groups
Harazaki et al. 2001[13]	10 patients in each of the 2 groups	increase in the WSL area in the 6 maxillary anterior teeth	ctr group: 286.84 mm^2 exp group: 140.76 mm^2	ctr group: 209.37 exp group: 38.05	<0.05	differences in the increase of the WSL areas between the laser-irradiated and control groups were significant
Hicks et al. 2004[16]	5 patients 14 teeth, assigned in 3 groups	lesion depth in PLM	G1 (ctr): 261 µm G2 (argon):147 µm G3 (fluoride+argon): 99 µm	G1 (ctr): 24 G2 (argon): 18 G3 (fluoride+argon): 12	<0.05	reduction in lesion depth: G2 vs G1: 44% G3 vs G1: 62% G3 vs G2: 32%
Miresmaeili et al. 2014[19]	16 patients 16 exp teeth 16 ctr teeth (in each patient, one of the premolars was exp and the other was ctr)	surface microhardness	ctr group: 183.9 VHN exp group: 301.81 VHN	ctr group: 72.08 exp group: 94.29	<0.001 CI: 95%	laser irradiation resulted in significantly higher surface microhardness as compared to the control teeth
Rechmann et al. 2011[18]	24 patients (12 patients with 4-week evaluation time + 12 patients with 12-week evaluation time) (the same teeth divided into the exp and ctr area)	sectional microhardness (overall relative mineral loss)	in the 4-week arm: ctr group: 737 ΔZ exp group: 402 ΔZ in the 12-week arm: ctr group: 1,076 ΔZ exp group: 135 ΔZ	in the 4-week arm: ctr group: 131 exp group: 85 in the 12-week arm: ctr group: 254 exp group: 98	0.04 0.002	in the 4-week arm: laser produced 46% demineralization inhibition in the 12-week arm: laser produced 86% demineralization inhibition
Suetenkov et al. 2015[20]	60 patients (30 in each of the 2 groups)	growth in caries intensity (DMFT and DMFS indices)	ctr group (traditional preventive procedure): Δ DMFT: 2.77 Δ DMFS: 2.66 exp group (laser+traditional preventive procedure): Δ DMFT: 1.05 Δ DMFS: 1.37	ctr group (traditional preventive procedure): Δ DMFT: 0.56 Δ DMFS: 0.30 exp group (laser+traditional preventive procedure): Δ DMFT: 0.14 Δ DMFS: 0.13	<0.001	growth of dental and surface caries intensity was significantly lower in the experimental group

CI – confidence interval; ctr – control; DMFT: count of Decayed, Missing and Filled Teeth; DMFS: count of Decayed, Missing and Filled tooth Surfaces; Δ DMFT and Δ DMFS – growth in caries intensity indices; exp – experimental; G – group; PLM – polarized light microscopy; VHN – Vickers hardness number (measurement unit for surface microhardness); WSL – white spot lesion; ΔZ – overall relative mineral loss (measured by plotting normalized volume percent mineral against distance from the enamel surface; vol% × µm).

The most effective and safest laser types and parameters for the prevention of enamel demineralization

Studies that compared the effectiveness of 2 or more laser beams in demineralization inhibition during orthodontic treatment were all in vitro.[21,22] Studies that compared the effect of different parameters of the same laser type were also in vitro and did not concern orthodontic treatment. There were no studies undertaken during orthodontic treatment comparing the improvement in demineralization resistance among different laser types or different laser settings.

Discussion

The prevention of demineralization or WSL formation during orthodontic treatment is one of the most difficult challenges orthodontists have to face. Many preventive procedures have been used in the literature for this purpose. Laser irradiation has been widely studied in vitro and showed its effectiveness in increasing enamel resistance to decalcification, suggesting that it could be useful during orthodontic treatment. As presented in the literature, many laser types have been used to prevent enamel demineralization around orthodontic appliances, including Er:YAG,[23–25] Nd:YAG,[13,21,22] CO_2,[18–22,26–28] diode,[29,30] and argon laser.[14–17,31,32] Although the clinical application of lasers during orthodontic treatment for a preventive purpose is still limited, the present review showed clinical effectiveness of laser irradiation in inhibiting enamel demineralization.

There were no clinical trials that applied Er:YAG or diode lasers during orthodontic treatment to prevent WSL formation.

In 3 studies, the application of argon laser irradiation on the enamel surface showed significant reduction in lesion depth in comparison with non-irradiated teeth, and its effect was significantly higher when it was combined with fluoride application,[14–16] but the sample sizes in these studies were small, with short follow-up periods. The effect of irradiation with an argon laser on WSL formation while curing the adhesives of orthodontic brackets was evaluated in 1 RCT lasting 1 year, but no significant effect on enamel demineralization was observed.[17]

Irradiation with a CO_2 laser had a significant effect on enamel microhardness around orthodontic brackets and it decreased mineral loss in comparison with non-irradiated enamel in 2 RCTs.[18,19] The wave lengths applied clinically were 9.6 µm and 10.6 µm, respectively. However, the effect of CO_2 lasers during orthodontic treatment was not evaluated for a long follow-up period.

The effect of Nd:YAG laser irradiation on existing WSLs was studied in only 1 clinical trial, with a 1-year follow-up.[13] The increases in the WSL area were significantly lower in the laser-irradiated group of patients in comparison with the control group. This type of laser had not been previously applied clinically on sound enamel during orthodontic treatment to prevent decalcification.

The effect of an Optodan laser on enamel demineralization was studied in a RCT by comparing the development of tooth caries intensity (growth of the Decayed, Missing and Filled Teeth index – ΔDMFT, and growth of the Decayed, Missing and Filled tooth Surfaces index – ΔDMFS) between the laser group and the control group for a 1-year follow-up period, and it showed significantly lower caries intensity in the lased group as compared to the control non-irradiated group.[20]

Changes in the enamel structure after laser irradiation were evaluated in 2 of the included studies by scanning electron microscopy. Miresmaeili et al. evaluated enamel surface changes by extracting 2 premolars (irradiated and control) of 1 patient after 1 week of CO_2 laser irradiation; the lased tooth showed melting of the enamel surface.[19] As studied in the literature, the prevention of caries by CO_2 laser irradiation could stem from reduced enamel permeability and solubility as a result of melting.[33,34] Harazaki et al. studied enamel changes after Nd:YAG irradiation in vitro.[13] The irradiated portion of the tooth had a smooth surface with a small number of cracks.

The limitations of this review are related primarily to the lack of high-level evidence from RCTs and the heterogeneity among studies in irradiation protocols, outcomes, follow-up periods, and methods of outcome measurement.

Conclusions

This review showed that laser irradiation may be effective in preventing demineralization during orthodontic treatment, but further studies are needed, including RCTs using different lasers, to evaluate which is the most effective laser and what settings should be used. There is also a need for longer follow-up periods to evaluate the longevity of treatment.

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