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Review Article

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Does photobiomodulation on the root surface decrease the occurrence of root resorption in reimplanted teeth? A systematic review of animal studies

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Conflict of Interest
No potential conflict of interest relevant to this article was reported.

ABSTRACT

This review aimed to answer the following question "Does photobiomodulation treatment of the root surface decrease the occurrence of root resorption in reimplanted teeth?" Electronic searches were performed in the MEDLINE/PubMed, Cochrane Library, Scopus, Web of Science, Embase, and Grey Literature Report databases. Risk of bias was evaluated using SYRCLE Risk of Bias tool. The Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) tool was used to assess the certainty of evidence. In total, 6 studies were included. Five studies reported a reduced occurrence of root resorption in teeth that received photobiomodulation treatment of the root surface prior to replantation. Only 1 study reported contradictory results. The photobiomodulation parameters varied widely among studies. GRADE assessment showed a low certainty of evidence. It can be inferred that photobiomodulation treatment of the root surface prior to replantation of teeth can reduce the occurrence of root resorption. Nonetheless, further clinical studies are needed.

Trial Registration: PROSPERO Identifier: CRD42022349891

Keywords: Avulsion; Laser therapy; Photobiomodulation; Root resorption; Tooth replantation

INTRODUCTION

Traumatic dental injuries (TDIs) comprise 5% of all injuries in children and young adults [1]. In 2018, the worldwide prevalence of TDIs was 15.2% for permanent teeth and 22.7% for primary teeth, with an incidence rate of 2.82 per 100 person-years [2]. TDIs exert a significant negative impact on the oral health-related quality of life of children and adolescents [3], and there are several risk factors associated with their occurrence, such as male sex, age [4,5], greater overjet, inadequate lip coverage, anterior open bite [4-6], overweight, a previous history of TDI, tongue piercing, the use of alcoholic beverages, and sports practice [5].

Among the injuries that can occur following trauma, avulsion is one of the most serious dental injuries. According to the International Association of Dental Traumatology (IADT),

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in situations of tooth avulsion, replantation should be the treatment of choice, with only a few situations precluding this procedure, such as severe caries or periodontal disease, an uncooperative patient, severe cognitive impairment requiring sedation, severe medical conditions such as immunosuppression, and severe cardiac conditions [7]. Nevertheless, the main complications associated with tooth avulsion are external inflammatory root resorption, with a prevalence of 23.2%, and/or replacement resorption, with a prevalence of 51% [8].

External inflammatory root resorption develops following injuries to the pulp and root cementum, and it is associated with the presence of bacterial infection beyond the damaged root surface, which acts a stimulus to clastic cells, contributing to a rapid progression of the resorptive process [9]. Replacement resorption is associated with severe damage to the root cementum (when more than 20% of the root surface is affected, resulting in the exposure of the root dentin) [10,11], the resorptive action of osteoclastic cells, and the subsequent deposition of bone tissue by osteoblastic cells [12].

To date, the only treatment recommended by the IADT for reducing the occurrence of root resorption is the use of systemic antibiotics [7]. Specifically, doxycycline is recommended due to its antimicrobial, anti-inflammatory, and antiresorptive effects [7]. However, the risk of tooth discoloration when using tetracycline or doxycycline, especially in patients under 12 years old [13], and the risk of bacterial resistance to the use of antibiotics [14] are major drawbacks related to the use of systemic antibiotics. Therefore, it seems to be necessary to investigate other treatment modalities in order to reduce the occurrence of root resorption.

Some studies have tested the local application of different substances, such as a gel containing enamel matrix proteins [15], sodium alendronate [16], and propolis and acidulated phosphate sodium fluoride [17], in attempts to reduce the occurrence of root resorption following tooth replantation. However, none of these experimental therapies were effective [15-17]. More recently, researchers have proposed directly applying photobiomodulation to the root surface prior to tooth replantation, aiming to induce morphological changes on the root surface to improve cell adhesion, proliferation, and the subsequent attachment of periodontal tissue [18-20], in addition to an antimicrobial effect [21-23]. These findings led to the assumption that the irradiation of root surfaces prior to replantation could decrease the incidence of root resorption, improving the prognosis of replanted avulsed teeth.

Considering the severe implications of tooth avulsion and the need to investigate alternative therapies to the use of systemic antibiotics, as well as the growing number of studies investigating the use of photobiomodulation on the root surface prior to tooth replantation, the present systematic review aimed to investigate the available evidence by addressing the following question: "Does photobiomodulation treatment of the root surface decrease the occurrence of root resorption in reimplanted teeth?"

MATERIALS AND METHODS

This systematic review followed the recommendations of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) [24], and the protocol was registered in the PROSPERO database (CRD42022349891).

Search strategy

Searches were independently conducted up to June 2022, without year or language restriction, by 2 examiners (T.W. and K.F.B.) in the following electronic databases: MEDLINE/PubMed, Cochrane Library, Scopus, Web of Science, Embase, and Grey Literature Report (grey literature search). The electronic search strategy employed the most cited descriptors in this field according to previous publications, combining Medical Subject Heading (MeSH) terms and text words (tw.). The Boolean operators "AND" and "OR" were applied to combine the terms and create a search strategy. **Supplementary Table 1** presents the search strategies for each database. Additional manual search of the reference lists of the selected studies was performed. All articles selected were imported into the Mendeley reference manager (Mendeley Ltd., London, UK) to catalog the references and facilitate the exclusion of duplicates.

Eligibility criteria

The eligibility criteria were selected according to the PICOS strategy [25-27], as follows:

- Population (P): extracted teeth in animal models;
- Intervention (I): photobiomodulation treatment of the root surface prior to replantation;
- Comparison (C): control group;
- Outcome (O): root resorption;
- Study design (S): studies in animal models.

Studies in which photobiomodulation was not applied directly in the root surface, studies in which root resorption was simulated by means of radicular grooves, studies in which animals presented systemic diseases; studies that evaluated other oral diseases (*e.g.*, periodontitis); systematic reviews with and without meta-analysis, reviews, letters, opinion articles, and conference abstracts were excluded.

Selection of the studies

Study selection was performed by 2 independent authors (T.W. and K.F.B.), who conducted the database search, removed duplicates and screened titles and abstracts. If the title and abstract were not sufficient to determine inclusion, the full text was read for a final decision. After that, potentially eligible studies were then read for full-text assessment using the PICOS criteria. Divergences between reviewers were solved by discussing with a third author (C.H.T.M.).

Data extraction

Two authors (T.W. and K.F.B.) performed data extraction independently. Disagreements were solved by discussing with a third author (C.H.T.M.). The following data were extracted from the studies: authors' names, year of publication, country of first author, animal model, sample size, investigated groups, samples per group, teeth evaluated, photobiomodulation protocol, additional procedures, extra-alveolar time prior to replantation, storage medium, time of outcome assessment, method of root resorption analysis, outcomes, and main findings. In case of missing information, the authors were contacted 3 times by e-mail at intervals of 1 week.

Qualitative assessment

The Systematic Review Centre for Laboratory Animal Experimentation Risk of Bias (SYRCLE RoB Tool) was used to assess the quality of the selected studies [28]. The SYRCLE RoB Tool evaluates 10 domains: selection bias, performance bias, detection bias, attrition bias,

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reporting bias, and other sources of bias. For each domain, a study was deemed to have a high risk of bias (if it did not meet 1 or more criteria); an unclear risk of bias (if it did not present the necessary data or partially met 1 or more criteria), or a low risk of bias (if all the requirements were met).

Certainty of evidence

To assess the certainty of the evidence of the included studies, an adapted methodology of the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) tool was used [29]. The GRADE tool has 5 domains that can be downgraded to reduce the assessment of the quality of the evidence. The following domains were included in this study: 1) risk of bias; 2) inconsistency; 3) indirectness; 4) imprecision; and 5) other considerations: assessment of publication bias, significant effect, plausible confounding, and dose-response gradient.

RESULTS

Study selection

The flow diagram of the search strategy is displayed in **Figure 1**.

The initial screening of databases resulted in 244 studies, with 46 excluded for being duplicates. From the analysis of the titles and abstracts of the 198 eligible papers, 9 studies

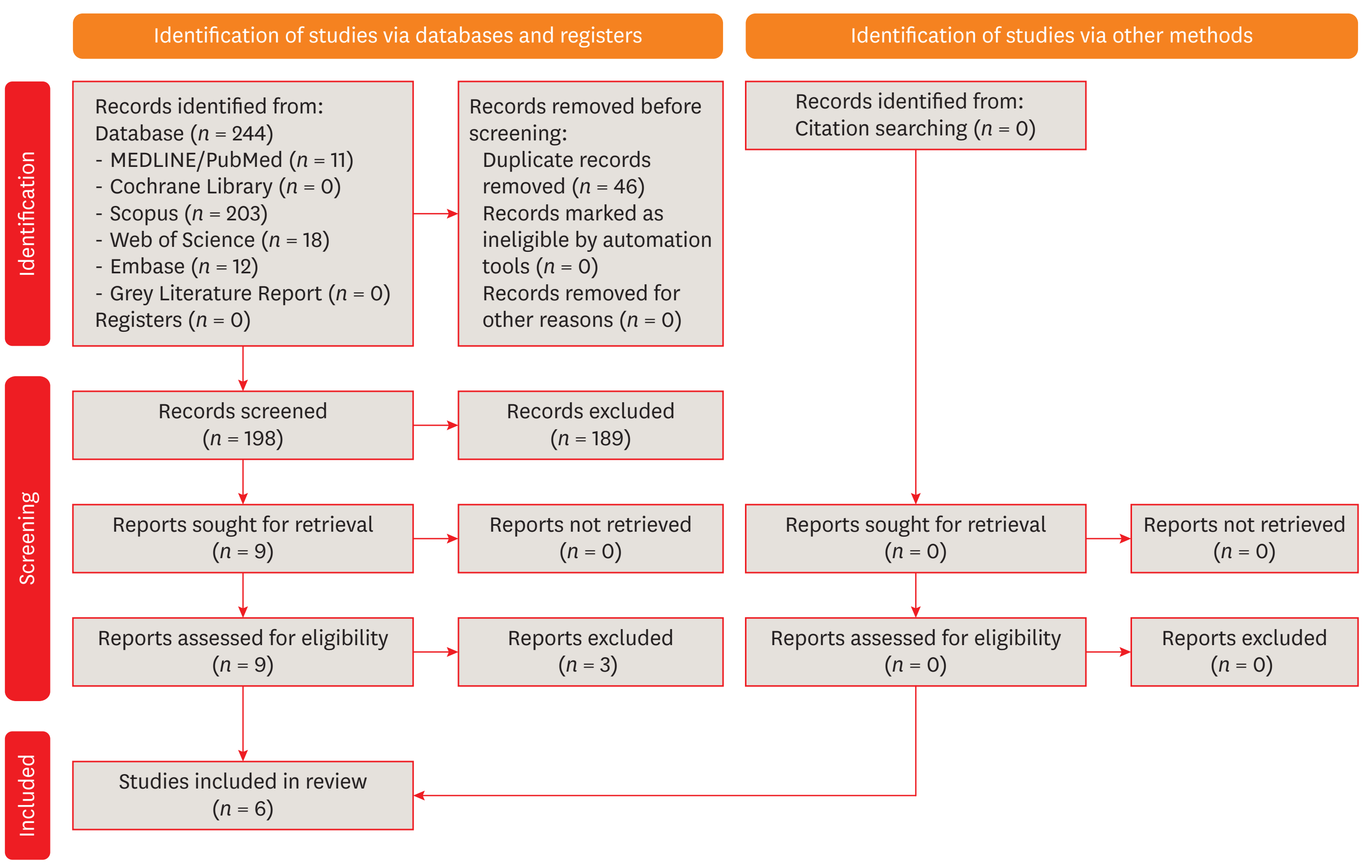

Figure 1. Systematic search process according to the PRISMA flow diagram.
PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis.

were selected for full-text reading [30-38]. After full-text reading, 3 studies were excluded [30-32]: 1 study for having performed simulated grooves in root resorption [30], 1 study for not having evaluated the occurrence of root resorption [31], and 1 study for not having applied photobiomodulation directly to the root surface [32].

Finally, 6 studies were included in the present systematic review [33-38].

Data extraction

The characteristics of the included studies are presented in **Table 1**.

All included studies performed their evaluation in maxillary incisors of rat models [33-38]. The photobiomodulation protocol, additional procedures, and storage medium varied among studies. The extra-alveolar time prior to replantation ranged from 0 minutes (immediate replantation) to 60 minutes.

Three studies assessed the outcomes after 15, 30 and 60 days [34-36]; 2 studies after 60 days only [33-38]; and one study after 15 and 30 days [37]. Moreover, root resorption was studied using histomorphometric [33,34,37]; radiographic [34,38]; histological [34,36,38]; and histomorphological [35] methods.

Five studies reported that the application of photobiomodulation on the root surface, prior to replantation, reduced the occurrence of external root resorption [34-38]. Only 1 study did not find any significant differences between the experimental and control groups [33]. Additionally, 1 study found that photobiomodulation in the buccal and palatal mucosa every 48 hours for 15 days resulted in a higher incidence of external inflammatory root resorption and ankylosis [36].

Qualitative assessment

Figure 2 presents the risk of bias assessment of the included studies [39].

The domains “allocation concealment,” “random housing,” “blinding of participants,” and “random outcome assessment were classified as having a high risk of bias in all studies. In the domain “baseline characteristics,” all studies were classified as presenting an unclear risk of bias. In the domain “random sequence generation,” 1 study was classified as having a high risk of bias [34], and the other studies as having an unclear risk of bias. In the domain “blinding of outcome assessors,” 1 study presented a high risk of bias [36], and the other studies a low risk of bias. All studies showed low risks of bias in the domains “incomplete outcome data,” “selective reporting,” and “other bias.”

Certainty of evidence

Table 2 summarizes the results of the GRADE assessment.

According to the recommendations for assessing the certainty of evidence from preclinical animal studies [29], the initial certainty was high. “Risk of bias” received a “very serious” classification, and for this reason, the overall certainty was downgraded. “Inconsistency,” “indirectness,” and “imprecision” were classified as “not serious.” In the “other considerations” domain, none of the components were verified and the certainty of evidence was not upgraded. Therefore, the overall certainty of evidence for the included studies was low.

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Table 1. Characteristics of the included studies

Authors – country	Year of publication	Animal model (sample size)	Investigated groups (samples per group)	Teeth evaluated	Photobiomodulation protocol	Additional procedures	Extra-alveolar time prior to replantation	Storage medium	Time of outcome assessment	Method of root resorption analysis	Outcomes	Main findings
Saito *et al*. [33] – Brazil	2011	Male rats (n = 60)	· Group 1: Control 1 (n = 10) · Group 2: Control 2 (n = 10) · Group 3: Control 3 (n = 10) · Group 4: Laser 1 (n = 10) · Group 5: Laser 2 (n = 10) · Group 6: Laser 3 (n = 10)	Maxillary right incisors	<u>Palatal root surface/ Alevolar socket</u> GaAlAs continuous-wave diode laser · Wavelength: 660 nm (palatal root surface), 830 nm (alveolar socket) · Output power: 30 mW (palatal root surface), 40 mW (alveolar socket) · Energy density: 57.14 J/cm^{-2} (each site) · Total energy: 4 J (each site) · Total time of irradiation: 2 min and 13 sec (palatal root surface), 1 min and 40 sec (alveolar socket)	· Groups 1 and 4: Asepsis with 1% iodine polyvinylpyrrolidone, and irrigation of the alveolar socket with saline solution · Groups 2, 3, 5, and 6: Removal of the dental papilla and enamel organ with scalpel, pulp extirpation, root canal irrigation with saline solution, root canal filling with calcium hydroxide · Asepsis with 1% iodine polyvinylpyrrolidone, and irrigation of the alveolar socket with saline solution (after laser application in groups 5 and 6)	· Group 1: Control 1–4 min · Group 2: Control 2–30 min · Group 3: Control 3–45 min · Group 4: Laser 1–4 min · Group 5: Laser 2–30 min · Group 6: Laser 3–45 min	· Groups 1 and 4: kept dry · Groups 2, 3, 5, and 6: saline solution	After 60 days	· Histomorphometric analysis	· No differences were found in inflammatory and replacement resorption among groups. · Areas of ankylosis were greater in group 5.	· Treatment of the root surface and the alveolar wound with low-level laser did not improve the healing process of immediate and delayed tooth replantation in rats.
Carvalho *et al.* [34] – Brazil	2012	Male rats (n = 60)	· Group 1: Negative control (n = 10) · Group 2: Positive control (n = 10) · Group 3: Continuous mode laser (n = 10) · Group 4: Pulse mode laser (n = 10)	Maxillary right incisors	<u>Root surface</u> GaAlAs high-power diode laser · Wavelength: 810 nm · Output power: 1,200 mW · Total time of irradiation: 30 sec (5 sec in each surface) · Incidence angulation: 45°	· Removal of the dental papilla, pulp extirpation, root canal preparation and irrigation with 1% sodium hypochlorite and EDTA-T · Root canal filling with calcium hydroxide (after laser application in groups 3 and 4) · Prior to laser application, immersion of extracted teeth in 1% sodium hypochlorite for 10 min, removal of remaining periodontal ligament with gauze, and washing with saline solution	· 60 min	· Kept dry	After 15, 30, and 60 days	· Radiographic analysis · Histomorphometric analysis · Histological analysis	· Histomorphometric and radiographic analyses showed lower incidence of root resorption in the irradiated groups, without differences between irradiated groups. · Resorption and ankylosis were observed in histological section after 30 and 60 days, except in group 3.	· Root surface treatments with high-powered diode laser irradiation prior to delayed replantation reduced the occurrence of external root resorption.

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Table 1. (Continued) Characteristics of the included studies

Authors – country	Year of publication	Animal model (sample size)	Investigated groups (samples per group)	Teeth evaluated	Photobiomodulation protocol	Additional procedures	Extra-alveolar time prior to replantation	Storage medium	Time of outcome assessment	Method of root resorption analysis	Outcomes	Main findings
Vilela *et al.* [35] – Brazil	2012	Male rats (n = 72)	· Group 1: Control (n = 36) · Group 2: Laser (n = 36)	Maxillary left incisor	Root surface/Alevolar socket InGaAlP continuous-wave diode laser · Wavelength: 685 nm (each site) · Output power: 50 mW (each site) · Spot size: 0.02 cm^2 · Optical power density: 2.5 W/cm^2 (each site) · Energy density: 200 J/cm^2 (each site) · Total energy: 4 J (each site) · Distance from root/irradiated tissue: 1 mm	· None	· Not reported	· Kept dry for 15 min and then stored in saline solution	After 15, 30 and 60 days	· Histomorphological analysis	· Increased root resorption in the control group was observed in all periods evaluated when compared to the laser group.	· Laser therapy resulted in less occurrence of root resorption.
Carvalho *et al.* [36] – Brazil	2016	Male rats (n = 60)	· Group 1: Control 1 (n = 15) · Group 2: Control 2 (n = 15) · Group 3: Laser (n = 15) · Group 4: Laser for 15 days (n = 15)	Maxillary right incisors	Root surface/Alevolar socket/Buccal and palatal mucosa Laser application in buccal and palatal mucosa only in group 4, every 48 hr for 15 days GaAlAs continuous-wave diode laser · Wavelength: 780 nm (each site) · Output power: 70 mW (each site) · Spot size: 0.04 cm^2 · Energy density: 16.8 J/cm^2 (root surface), 4.2 J/cm^2 (alveolar socket), 4.2 J/cm^2 (buccal and palatal mucosa) · Total time of irradiation: 320 sec (root surface), 60 sec (alveolar socket), 120 sec (buccal and palatal mucosa)	· Removal of the dental papilla and enamel organ with scalpel, pulp extirpation, root canal irrigation with saline solution, root canal filling with calcium hydroxide · Prior to replantation, irrigation of the alveolar socket with saline solution	· 40 min	· Group 1: kept dry · Groups 2, 3, and 4: UHT skimmed milk	After 15, 30 and 60 days	· Histological analysis	· After 15 days, group 4 exhibited moderate external inflammatory resorption. · After 30 days, groups 1, 2, and 4 presented intense external inflammatory root resorption, and different levels of ankylosis. · Group 3 remained without external inflammatory root resorption and ankylosis up to 60 days.	· Laser application to the root surface and alveolar socket resulted in no external inflammatory root resorption or ankylosis. · Association of laser application in buccal and palatal mucosa every 48 hours for 15 days resulted in a higher incidence of external inflammatory root resorption and ankylosis.

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Table 1. (Continued) Characteristics of the included studies

Authors – country	Year of publication	Animal model (sample size)	Investigated groups (samples per group)	Teeth evaluated	Photobiomodulation protocol	Additional procedures	Extra-alveolar time prior to replantation	Storage medium	Time of outcome assessment	Method of root resorption analysis	Outcomes	Main findings
Matos *et al.* [37] – Brazil	2016	Male rats (n = 60)	· Group 1: Control 1 (n = 10) · Group 2: Control 2 (n = 10) · Group 3: Control 3 (n = 10) · Group 4: Laser 1 (n = 10) · Group 5: Laser 2 (n = 10) · Group 6: Laser 3 (n = 10)	Maxillary right incisors	Root surface/Alevolar socket/Buccal and palatal mucosa Laser application in buccal and palatal mucosa, every 48 hr for 5 sessions GaAlAs continuous-wave diode laser (root surface and alveolar socket) InGaAlP continuous-wave diode laser (buccal and palatal mucosa) · Wavelength: 808nm (root surface and alveolar socket), 660 nm (buccal and palatal mucosa) · Output power: 100 mW (each site) · Optical power density: 3.6 W/cm^2 (each site) · Energy density: 61 J/cm^{-2} (each site) · Total energy: 10.2 J (root surface and alveolar socket), 17 J (buccal and palatal mucosa) · Total time of irradiation: 102 sec (root surface), 17 sec (alveolar socket), 170 sec (buccal and palatal mucosa)	· Removal of the dental papilla with a scalpel, pulp extirpation, root canal irrigation with saline solution, root canal filling with calcium hydroxide · Prior to replantation, irrigation of the alveolar socket with saline solution	45 min	· Groups 1 and 4: kept dry · Groups 2 and 5: UHT cow milk · Groups 3 and 6: soy milk	After 15 and 30 days	· Histomorphometric analysis	· After 30 days, group 1 presented larger areas of root resorption. · After 30 days, groups 2 and 3 presented no difference in root resorption. · After 30 days, laser application significantly reduced root resorption in group 4. · After 30 days, laser application reduced root resorption in groups 5 and 6, without differences when compared to groups 2 and 3.	· Laser application, as well as cow and soy milk, reduced the occurrence of root resorption

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Table 1. (Continued) Characteristics of the included studies

Authors – country	Year of publication	Animal model (sample size)	Investigated groups (samples per group)	Teeth evaluated	Photobiomodulation protocol	Additional procedures	Extra-alveolar time prior to replantation	Storage medium	Time of outcome assessment	Method of root resorption analysis	Outcomes	Main findings
Carvalho *et al.* [38] – Brazil	2017	Male rats (*n* = 50)	· Group 1: Negative control (*n* = 10) · Group 2: Positive control (*n* = 10) · Group 3: Fibroblast growth gel (*n* = 10) · Group 4: Laser (*n* = 10) · Group 5: Laser + Fibroblast growth gel (*n* = 10)	Maxillary right incisors	Root surface Continuous-wave high-power diode laser · Wavelength: 808 ± 10 nm · Output power: 1,200 mW · Optical power density: 7.14 W/cm² · Energy density: 214.3 J/cm² · Total energy: 45 J · Incidence angulation: 45° · Total time of irradiation: 30 sec (5 sec on each surface)	Removal of dental papilla with scalpel in all groups · Groups 3 and 5: Application of 50 µg of 0.2% basic fibroblast growth gel in 3% hydroxypropylmethylcellulose gel in the palatal root surface and in the alveolar socket · Groups 3, 4, and 5: Pulp extirpation, root canal preparation and irrigation with 1% sodium hypochlorite and EDTA-T, and root canal filling with calcium hydroxide · Prior to laser application, immersion of extracted teeth in 1% sodium hypochlorite for 10 min, removal of remaining periodontal ligament with gauze, and washing with saline solution · Prior to replantation, irrigation of the alveolar socket with saline solution	· Group 2: immediate replantation · Groups 1, 3, 4, and 5: 60 min	· Kept dry	After 60 days	· Radiographic analysis · Histological analysis	· Radiographic analysis showed fewer resorptive areas in group 5 than in the negative control. · Radiographically, groups 3, 4, 5, and the positive control did not differ regarding areas of external root resorption. · Histological analysis showed lower mean values of ankylosis, replacement, and inflammatory resorption for group 4 than in the negative control, without differing from positive control.	· Laser application, with or without application of fibroblast growth gel, reduced the occurrence of external root resorption and ankylosis.

GaAlAs, gallium-aluminum-arsenate; InGaAlP, indium-gallium-aluminum-phosphorus; UHT, ultra-heat treatment; EDTA-T, ethylenediaminetetraacetic acid-texapon.

Table 2. Certainty of the evidence from the included studies according to the GRADE approach for preclinical animal studies

Number of studies	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Overall certainty of evidence
6 studies	Very serious*	Not serious	Not serious	Not serious	None	⊕⊕○○ LOW

GRADE, Grading of Recommendations, Assessment, Development, and Evaluations.
*Several domains had studies with an unclear or high risk of bias.

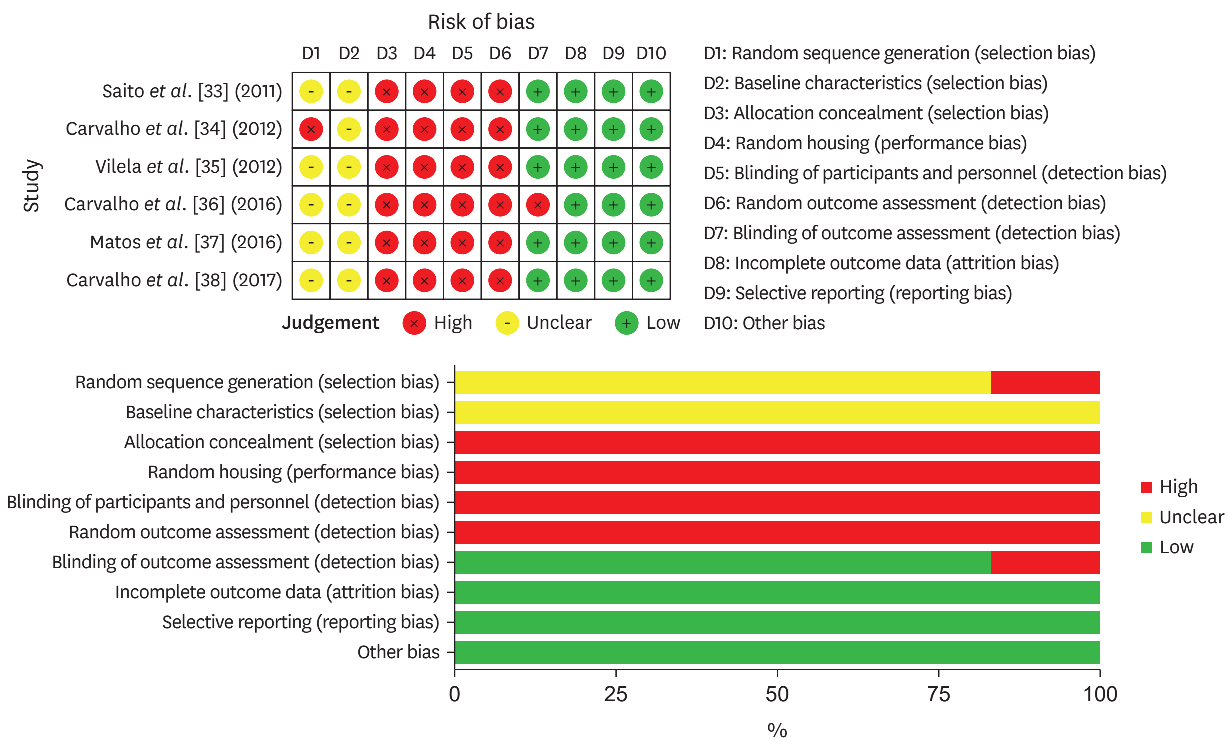

Figure 2. Quality assessment of the included studies according to the risk of bias tool for preclinical animal studies – (SYRCLE's RoB tool).

DISCUSSION

The prognosis of avulsed teeth following replantation is unpredictable. Many teeth are lost, mainly due to the occurrence of root resorption [40,41]. Therefore, there is a constant need to investigate alternative therapies to reduce the incidence of root resorption. For this reason, in the present systematic review, searches were performed in 6 electronic databases, aiming to evaluate the available evidence on the effectiveness of photobiomodulation of the root surface prior to replantation of teeth on reducing the occurrence of root resorption.

When investigating the effects of photobiomodulation, it is important to understand that it involves several parameters. Among these, wavelength is the most important, since it determines the light penetration depth into the tissues [42], which is also associated with the thermal effect caused by the light [43]. In general, a red-light laser presents a wavelength ranging from 620 to 740 nm, and an infrared-light laser has a wavelength ranging from 780 to 1000 nm [43]. Parameters such as energy density and duration of irradiation are also important because they determine the irradiation dose absorbed by the cells, directly affecting the expected biological effects [44].

Methodologies varied widely among the included studies. However, when evaluating the information presented by those studies, there are a few possible explanations for their findings. Only 2 studies [33,35] performed photobiomodulation using a low-level red-light laser (660 nm and 685 nm, respectively). The red-light laser mechanism of action involves stimulating cell metabolism and tissue repair, favoring a greater effectiveness and response of tissues exposed to an insult [45]. This method also exerts anti-inflammatory effect, by modulating cell influx, hemorrhagic formation, and inflammatory metabolites [45], even in the presence of bacterial by-products [46]. One of these studies concluded that photobiomodulation of the root surface did not decrease the occurrence of root resorption [33]; while the other concluded that it resulted in less occurrence of root resorption [35]. These inconsistent findings may be related to the manner in which photobiomodulation was applied. While in the study by Saito *et al.* [33], photobiomodulation was applied only to the palatal root surface of teeth and, after replantation, to the middle third of the palatal surface of the alveolar socket with an infrared light (830 nm); in the study by Vilela *et al.* [35], application was performed over the entire root surface, on the interior of the alveolus and, after replantation, on the entrance and palatal surface of the alveolar socket. Therefore, it is possible to hypothesize that the non-homogeneous photobiomodulation application in the study by Saito *et al.* [33] could be the reason for the absence of an improved protective effect against root resorption in the irradiated groups, since only 1 root surface was irradiated, and the non-irradiated surface did not receive a sufficient amount of radiation to stimulate the cell metabolism, tissue repair, and anti-inflammatory effects.

Two studies [36,37] investigated the effects of low-level infrared-light lasers (780 nm and 808 nm, respectively) and reported a lower occurrence of root resorption when laser application was performed. In addition to the stimulation of cell metabolism and tissue repair, favoring a greater effectiveness and response of tissues exposed to an insult [47], this method demonstrated direct effects on the proliferation, attachment, spreading, and orientation of periodontal ligament fibroblasts [20,48,49]. It has also been suggested that this treatment can promote a greater increase of collagen type I and III, accelerating the dynamic of collagenization and facilitating a more favorable repair process [50,51]. Thus, it can be hypothesized that the application of low-level infrared-light laser on the root surface can maintain the cell viability of the periodontal ligament attached to the root surface, as well as locally stimulating repair and controlling the inflammatory response, thereby preventing the occurrence of root resorption.

Two studies [34,38] investigated the use of high-power infrared-light lasers (810 nm and 808 nm, respectively) and also concluded that their application reduced the occurrence of root resorption. In addition to the above-mentioned effects promoted by infrared light, the high-power laser setting promoted morphological alterations of the root surface, such as melting and fusion of the dental structure, thus making it more homogeneous, favoring the adhesion of connective tissue fibers and cells, facilitating new cementum formation, and rendering the surface a more resistant to the action of microorganisms and clastic cells [19,52,53].

As an additional finding, 1 study [36] reported that regular application (every 48 hours for 15 days) of infrared-light laser photobiomodulation to the buccal and palatal mucosa resulted in a higher incidence of external inflammatory resorption and ankylosis. The authors hypothesized that this finding may be related to the stimulation of differentiation and activation of osteoclasts [36]. It has been suggested that mitochondrial cytochrome C absorbs the energy of the laser and this absorption enhances cellular activity by increasing

ATP synthesis [54]. Therefore, since osteoclasts are multinucleated cells with highly active mitochondria, the laser rapidly affects these cells [55,56].

Regarding the risk of bias assessment of the included studies, several drawbacks were observed. None of the studies had information regarding allocation concealment, methods of randomly housing the animals, approaches to blinding researchers, or whether the animals were selected at random for outcome assessment. Thus, in the "allocation concealment," "random housing," "blinding of participants and personnel," and "random outcome assessment" domains, a high risk of bias was attributed to all studies. Five studies [33,35-38] stated that the animals were randomized, but did not describe how this randomization was performed; and 1 study [34] did not provide information about random sequence generation at all. Therefore, an unclear and high risk of bias in the "random sequence generation" domain was attributed to these studies, respectively. Regarding the "baseline characteristics" domain, authors should report the characteristics of the animals used in the study, including information on sex, age and weight. All studies had an unclear risk of bias, as they provided partial information on these characteristics. In the "blinding of outcome assessment" domain, only 1 study [36] had a high risk of bias because it did not contain information on whether the outcomes were evaluated in a blinded manner. Finally, in the "incomplete outcome data," "selective reporting," and "other bias" domains, all studies had low risks of bias.

Based on the guidelines for assessing the certainty of evidence in preclinical animal studies [29], the certainty was initially classified as high. Due to the limitations presented by the included studies, during the risk of bias assessment, the domain "risk of bias" was classified as "very serious" and the initial certainty was downgraded 2 levels. No limitations were detected in the domains "imprecision," "indirectness," and "inconsistency." Since no other considerations (assessment of publication bias, significant effect, plausible confounding, and dose-response gradient) were verified, the "other considerations" domain remained unchanged. Therefore, the GRADE analysis demonstrated a low certainty of evidence.

Despite having been performed with an *a priori* protocol involving systematic searches of 6 electronic databases, the present systematic review has some limitations. First, it is known that the storage medium in which the avulsed tooth is kept prior to replantation can influence the periodontal ligament cell viability [57]. Only 1 study evaluated 2 storage media (soy and UHT cow milk) and did not find differences between groups [37]. Therefore, it was not possible to determine whether the storage medium influenced the investigated outcomes. Additionally, it was not possible to determine whether any of the tested protocols had any advantage over another, since different protocols were not tested between groups in the same study.

CONCLUSION

Based on the presented results, it is possible to infer, with a low certainty of evidence, that the application of photobiomodulation to the root surface of teeth prior to replantation can reduce the occurrence of root resorption. Further well-designed studies are needed to improve the quality of the available evidence and to determine a clinical protocol with standardized laser parameters.

SUPPLEMENTARY MATERIAL

Supplementary Table 1

Search strategy in each database

Click here to view

REFERENCES

1. Levin L, Day PF, Hicks L, O'Connell A, Fouad AF, Bourguignon C, Abbott PV. International Association of Dental Traumatology guidelines for the management of traumatic dental injuries: general introduction. Dent Traumatol 2020;36:309-313.
PUBMED | CROSSREF
2. Petti S, Glendor U, Andersson L. World traumatic dental injury prevalence and incidence, a meta-analysis-one billion living people have had traumatic dental injuries. Dent Traumatol 2018;34:71-86.
PUBMED | CROSSREF
3. Antunes LA, Lemos HM, Milani AJ, Guimarães LS, Küchler EC, Antunes LS. Does traumatic dental injury impact oral health-related to quality of life of children and adolescents? Systematic review and meta-analysis. Int J Dent Hyg 2020;18:142-162.
PUBMED | CROSSREF
4. Corrêa-Faria P, Martins CC, Bönecker M, Paiva SM, Ramos-Jorge ML, Pordeus IA. Clinical factors and socio-demographic characteristics associated with dental trauma in children: a systematic review and meta-analysis. Dent Traumatol 2016;32:367-378.
PUBMED | CROSSREF
5. Magno MB, Nadelman P, Leite KL, Ferreira DM, Pithon MM, Maia LC. Associations and risk factors for dental trauma: a systematic review of systematic reviews. Community Dent Oral Epidemiol 2020;48:447-463.
PUBMED | CROSSREF
6. Vieira WA, Pecorari VG, Gabriel PH, Vargas-Neto J, Santos EC, Gomes BP, Ferraz CC, Almeida JF, Marciano M, de-Jesus-Soares A. The association of inadequate lip coverage and malocclusion with dental trauma in Brazilian children and adolescents - a systematic review and meta-analysis. Dent Traumatol 2022;38:4-19.
PUBMED | CROSSREF
7. Fouad AF, Abbott PV, Tsilingaridis G, Cohenca N, Lauridsen E, Bourguignon C, O'Connell A, Flores MT, Day PF, Hicks L, Andreasen JO, Cehreli ZC, Harlamb S, Kahler B, Oginni A, Semper M, Levin L; International Association of Dental Traumatology. International Association of Dental Traumatology guidelines for the management of traumatic dental injuries: 2. Avulsion of permanent teeth. Dent Traumatol 2020;36:331-342.
PUBMED | CROSSREF
8. Souza BD, Dutra KL, Kuntze MM, Bortoluzzi EA, Flores-Mir C, Reyes-Carmona J, Felippe WT, Porporatti AL, De Luca Canto G. Incidence of root resorption after the replantation of avulsed teeth: a meta-analysis. J Endod 2018;44:1216-1227.
PUBMED | CROSSREF
9. Andreasen JO. Relationship between surface and inflammatory resorption and changes in the pulp after replantation of permanent incisors in monkeys. J Endod 1981;7:294-301.
PUBMED | CROSSREF
10. Andreasen JO, Kristerson L. The effect of limited drying or removal of the periodontal ligament. Periodontal healing after replantation of mature permanent incisors in monkeys. Acta Odontol Scand 1981;39:1-13.
PUBMED | CROSSREF
11. Andreasen JO. Periodontal healing after replantation of traumatically avulsed human teeth: assessment by mobility testing and radiography. Acta Odontol Scand 2009;33:325-333.
CROSSREF
12. Fuss Z, Tsesis I, Lin S. Root resorption--diagnosis, classification and treatment choices based on stimulation factors. Dent Traumatol 2003;19:175-182.
PUBMED | CROSSREF
13. Andreasen JO, Storgaard Jensen S, Sae-Lim V. The role of antibiotics in presenting healing complications after traumatic dental injuries: a literature review. Endod Topics 2006;14:80-92.
CROSSREF

14. Murray CJ, Ikuta KS, Sharara F, Swetschinski L, Robles Aguilar G, Gray A, Han C, Bisignano C, Rao P, Wool E, Johnson SC, Browne AJ, Chipeta MG, Fell F, Hackett S, Haines-Woodhouse G, Kashef Hamadani BH, Kumaran EA, McManigal B, Achalapong S, Agarwal R, Akech S, Albertson S, Amuasi J, Andrews J, Aravkin A, Ashley E, Babin FX, Bailey F, Baker S, Basnyat B, Bekker A, Bender R, Berkley JA, Bethou A, Bielicki J, Boonkasidecha S, Bukosia J, Carvalheiro C, Castañeda-Orjuela C, Chansamouth V, Chaurasia S, Chiurchiù S, Chowdhury F, Clotaire Donatien R, Cook AJ, Cooper B, Cressey TR, Criollo-Mora E, Cunningham M, Darboe S, Day NP, De Luca M, Dokova K, Dramowski A, Dunachie SJ, Duong Bich T, Eckmanns T, Eibach D, Emami A, Feasey N, Fisher-Pearson N, Forrest K, Garcia C, Garrett D, Gastmeier P, Giref AZ, Greer RC, Gupta V, Haller S, Haselbeck A, Hay SI, Holm M, Hopkins S, Hsia Y, Iregbu KC, Jacobs J, Jarovsky D, Javanmardi F, Jenney AW, Khorana M, Khusuwan S, Kissoon N, Kobeissi E, Kostyanev T, Krapp F, Krumkamp R, Kumar A, Kyu HH, Lim C, Lim K, Limmathurotsakul D, Loftus MJ, Lunn M, Ma J, Manoharan A, Marks F, May J, Mayxay M, Mturi N, Munera-Huertas T, Musicha P, Musila LA, Mussi-Pinhata MM, Naidu RN, Nakamura T, Nanavati R, Nangia S, Newton P, Ngoun C, Novotney A, Nwakanma D, Obiero CW, Ochoa TJ, Olivas-Martinez A, Olliaro P, Ooko E, Ortiz-Brizuela E, Ounchanum P, Pak GD, Paredes JL, Peleg AY, Perrone C, Phe T, Phommasone K, Plakkal N, Ponce-de-Leon A, Raad M, Ramdin T, Rattanavong S, Riddell A, Roberts T, Robotham JV, Roca A, Rosenthal VD, Rudd KE, Russell N, Sader HS, Saengchan W, Schnall J, Scott JA, Seekaew S, Sharland M, Shivamallappa M, Sifuentes-Osornio J, Simpson AJ, Steenkeste N, Stewardson AJ, Stoeva T, Tasak N, Thaiprakong A, Thwaites G, Tigoi C, Turner C, Turner P, van Doorn HR, Velaphi S, Vongpradith A, Vongsouvath M, Vu H, Walsh T, Walson JL, Waner S, Wangrangsimakul T, Wannapinij P, Wozniak T, Young Sharma TE, Yu KC, Zheng P, Sartorius B, Lopez AD, Stergachis A, Moore C, Dolecek C, Naghavi M; Antimicrobial Resistance Collaborators. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet 2022;399:629-655.
PUBMED | CROSSREF

15. Lam K, Sae-Lim V. The effect of Emdogain gel on periodontal healing in replanted monkeys' teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;97:100-107.
PUBMED | CROSSREF

16. Lustosa-Pereira A, Garcia RB, de Moraes IG, Bernardineli N, Bramante CM, Bortoluzzi EA. Evaluation of the topical effect of alendronate on the root surface of extracted and replanted teeth. Microscopic analysis on rats' teeth. Dent Traumatol 2006;22:30-35.
PUBMED | CROSSREF

17. Gulinelli JL, Panzarini SR, Fattah CM, Poi WR, Sonoda CK, Negri MR, Saito CT. Effect of root surface treatment with propolis and fluoride in delayed tooth replantation in rats. Dent Traumatol 2008;24:651-657.
PUBMED | CROSSREF

18. Schwarz F, Pütz N, Georg T, Reich E. Effect of an Er:YAG laser on periodontally involved root surfaces: an *in vivo* and *in vitro* SEM comparison. Lasers Surg Med 2001;29:328-335.
PUBMED | CROSSREF

19. Feist IS, De Micheli G, Carneiro SR, Eduardo CP, Miyagi S, Marques MM. Adhesion and growth of cultured human gingival fibroblasts on periodontally involved root surfaces treated by Er:YAG laser. J Periodontol 2003;74:1368-1375.
PUBMED | CROSSREF

20. Hakki SS, Korkusuz P, Berk G, Dundar N, Saglam M, Bozkurt B, Purali N. Comparison of Er,Cr:YSGG laser and hand instrumentation on the attachment of periodontal ligament fibroblasts to periodontally diseased root surfaces: an *in vitro* study. J Periodontol 2010;81:1216-1225.
PUBMED | CROSSREF

21. Kreisler M, Kohnen W, Beck M, Al Haj H, Christoffers AB, Götz H, Duschner H, Jansen B, D'Hoedt B. Efficacy of NaOCl/H_2O_2 irrigation and GaAlAs laser in decontamination of root canals *in vitro*. Lasers Surg Med 2003;32:189-196.
PUBMED | CROSSREF

22. de Souza EB, Cai S, Simionato MR, Lage-Marques JL. High-power diode laser in the disinfection in depth of the root canal dentin. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:e68-e72.
PUBMED | CROSSREF

23. Akiyama F, Aoki A, Miura-Uchiyama M, Sasaki KM, Ichinose S, Umeda M, Ishikawa I, Izumi Y. *In vitro* studies of the ablation mechanism of periodontopathic bacteria and decontamination effect on periodontally diseased root surfaces by erbium:yttrium-aluminum-garnet laser. Lasers Med Sci 2011;26:193-204.
PUBMED | CROSSREF

24. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
PUBMED | CROSSREF

25. Maia LC, Antonio AG. Systematic reviews in dental research. A guideline. J Clin Pediatr Dent 2012;37:117-124.
PUBMED | CROSSREF

26. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA; PRISMA-P Group. Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 statement. Syst Rev 2015;4:1.
PUBMED | CROSSREF

27. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann T, Mulrow CD, Shamseer L, Moher D. Mapping of reporting guidance for systematic reviews and meta-analyses generated a comprehensive item bank for future reporting guidelines. J Clin Epidemiol 2020;118:60-68.
PUBMED | CROSSREF

28. Hooijmans CR, Rovers MM, de Vries RB, Leenaars M, Ritskes-Hoitinga M, Langendam MW. SYRCLE's risk of bias tool for animal studies. BMC Med Res Methodol 2014;14:43.
PUBMED | CROSSREF

29. Hooijmans CR, de Vries RBM, Ritskes-Hoitinga M, Rovers MM, Leeflang MM, IntHout J, Wever KE, Hooft L, de Beer H, Kuijpers T, Macleod MR, Sena ES, Ter Riet G, Morgan RL, Thayer KA, Rooney AA, Guyatt GH, Schünemann HJ, Langendam MW; GRADE Working Group. Facilitating healthcare decisions by assessing the certainty in the evidence from preclinical animal studies. PLoS One 2018;13:e0187271.
PUBMED | CROSSREF

30. Friedman S, Komorowski R, Maillet W, Nguyen HQ, Torneck CD. Susceptibility of Nd:YAG laser-irradiated root surfaces in replanted teeth to external inflammatory resorption. Endod Dent Traumatol 1998;14:225-231.
PUBMED | CROSSREF

31. Panzarini SR, Okamoto R, Poi WR, Sonoda CK, Pedrini D, da Silva PE, Saito CT, Marão HF, Sedlacek P. Histological and immunohistochemical analyses of the chronology of healing process after immediate tooth replantation in incisor rat teeth. Dent Traumatol 2013;29:15-22.
PUBMED | CROSSREF

32. Pigatto Mitihiro D, de Paula Ramos S, Corazza Montero J, Alves Campos A, de Oliveira Toginho Filho D, Dezan Garbelini CC. Effects of near-infrared LED therapy on experimental tooth replantation in rats. Dent Traumatol 2017;33:32-37.
PUBMED | CROSSREF

33. Saito CT, Gulinelli JL, Panzarini SR, Garcia VG, Okamoto R, Okamoto T, Sonoda CK, Poi WR. Effect of low-level laser therapy on the healing process after tooth replantation: a histomorphometrical and immunohistochemical analysis. Dent Traumatol 2011;27:30-39.
PUBMED | CROSSREF

34. Carvalho ES, Costa FT, Campos MS, Anbinder AL, Neves AC, Habitante SM, Lage-Marques JL, Raldi DP. Root surface treatment using diode laser in delayed tooth replantation: radiographic and histomorphometric analyses in rats. Dent Traumatol 2012;28:429-436.
PUBMED | CROSSREF

35. Vilela RG, Gjerde K, Frigo L, Leal Junior EC, Lopes-Martins RA, Kleine BM, Prokopowitsch I. Histomorphometric analysis of inflammatory response and necrosis in re-implanted central incisor of rats treated with low-level laser therapy. Lasers Med Sci 2012;27:551-557.
PUBMED | CROSSREF

36. de Carvalho FB, Andrade AS, Barbosa AF, Aguiar MC, Cangussu MC, Pinheiro AL, Ramalho LM. Evaluation of laser phototherapy (λ 780 nm) after dental replantation in rats. Dent Traumatol 2016;32:488-494.
PUBMED | CROSSREF

37. Matos FS, Godolphim FJ, Correia AM, de Albuquerque Júnior RL, Paranhos LR, Rode SM, Ribeiro MA. Effect of laser photobiomodulation on the periodontal repair process of replanted teeth. Dent Traumatol 2016;32:402-408.
PUBMED | CROSSREF

38. Carvalho ED, Rosa RH, Pereira FM, Anbinder AL, Mello I, Habitante SM, Raldi DP. Effects of diode laser irradiation and fibroblast growth factor on periodontal healing of replanted teeth after extended extra-oral dry time. Dent Traumatol 2017;33:91-99.
PUBMED | CROSSREF

39. McGuinness LA, Higgins JP. Risk-of-bias VISualization (robvis): an R package and Shiny web app for visualizing risk-of-bias assessments. Res Synth Methods 2021;12:55-61.
PUBMED | CROSSREF

40. Hecova H, Tzigkounakis V, Merglova V, Netolicky J. A retrospective study of 889 injured permanent teeth. Dent Traumatol 2010;26:466-475.
PUBMED | CROSSREF

41. Soares AJ, Gomes BP, Zaia AA, Ferraz CC, de Souza-Filho FJ. Relationship between clinical-radiographic evaluation and outcome of teeth replantation. Dent Traumatol 2008;24:183-188.
PUBMED | CROSSREF

42. Ash C, Dubec M, Donne K, Bashford T. Effect of wavelength and beam width on penetration in light-tissue interaction using computational methods. Lasers Med Sci 2017;32:1909-1918.
PUBMED | CROSSREF

43. Cios A, Cieplak M, Szymański Ł, Lewicka A, Cierniak S, Stankiewicz W, Mendrycka M, Lewicki S. Effect of different wavelengths of laser irradiation on the skin cells. Int J Mol Sci 2021;22:2437.
PUBMED | CROSSREF

44. Basso FG, Pansani TN, Cardoso LM, Citta M, Soares DG, Scheffel DS, Hebling J, de Souza Costa CA. Epithelial cell-enhanced metabolism by low-level laser therapy and epidermal growth factor. Lasers Med Sci 2018;33:445-449.
PUBMED | CROSSREF

45. Lopes-Martins RAB, Penna SC, Joensen J, Iversen VV, Bjordal JM. Low-level laser therapy [LLLT] in inflammatory and rheumatic diseases: a review of therapeutic mechanisms. Curr Rheumatol Rev 2007;3:147-154.
CROSSREF

46. Lee JH, Chiang MH, Chen PH, Ho ML, Lee HE, Wang YH. Anti-inflammatory effects of low-level laser therapy on human periodontal ligament cells: *in vitro* study. Lasers Med Sci 2018;33:469-477.
PUBMED | CROSSREF

47. Fujimura T, Mitani A, Fukuda M, Mogi M, Osawa K, Takahashi S, Aino M, Iwamura Y, Miyajima S, Yamamoto H, Noguchi T. Irradiation with a low-level diode laser induces the developmental endothelial locus-1 gene and reduces proinflammatory cytokines in epithelial cells. Lasers Med Sci 2014;29:987-994.
PUBMED | CROSSREF

48. Kreisler M, Christoffers AB, Willershausen B, d'Hoedt B. Effect of low-level GaAlAs laser irradiation on the proliferation rate of human periodontal ligament fibroblasts: an *in vitro* study. J Clin Periodontol 2003;30:353-358.
PUBMED | CROSSREF

49. Kreisler M, Christoffers AB, Al-Haj H, Willershausen B, d'Hoedt B. Low level 809-nm diode laser-induced *in vitro* stimulation of the proliferation of human gingival fibroblasts. Lasers Surg Med 2002;30:365-369.
PUBMED | CROSSREF

50. Marinho RR, Matos RM, Santos JS, Ribeiro MA, Smaniotto S, Barreto EO, Ribeiro RA, Lima RC Jr, Albuquerque RL Jr, Thomazzi SM. Potentiated anti-inflammatory effect of combined 780 nm and 660 nm low level laser therapy on the experimental laryngitis. J Photochem Photobiol B 2013;121:86-93.
PUBMED | CROSSREF

51. Santos NR, de M Sobrinho JB, Almeida PF, Ribeiro AA, Cangussú MC, dos Santos JN, Pinheiro AL. Influence of the combination of infrared and red laser light on the healing of cutaneous wounds infected by Staphylococcus aureus. Photomed Laser Surg 2011;29:177-182.
PUBMED | CROSSREF

52. Raldi DP, Mello I, Neves AC, Habitante SM, Miyagi SS, Lage-Marques JL. Attachment of cultured fibroblasts and ultrastructural analysis of simulated cervical resorptions treated with high-power lasers and MTA. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;109:e154-e161.
PUBMED | CROSSREF

53. Haypek P, Zezell DM, Bachmann L, Marques MM. Interaction between high-power diode laser and dental root surface. Thermal, morphological and biocompatibility analysis. J Oral Laser Applic 2006;6:101-109.

54. Karu T. Primary and secondary mechanisms of action of visible to near-IR radiation on cells. J Photochem Photobiol B 1999;49:1-17.
PUBMED | CROSSREF

55. Aihara N, Yamaguchi M, Kasai K. Low-energy irradiation stimulates formation of osteoclast-like cells via RANK expression *in vitro*. Lasers Med Sci 2006;21:24-33.
PUBMED | CROSSREF

56. Nicola RA, Jorgetti V, Rigau J, Pacheco MT, dos Reis LM, Zângaro RA. Effect of low-power GaAlAs laser (660 nm) on bone structure and cell activity: an experimental animal study. Lasers Med Sci 2003;18:89-94.
PUBMED | CROSSREF

57. De Brier N, O D, Borra V, Singletary EM, Zideman DA, De Buck E; International Liaison Committee on Resuscitation First Aid Task Force. Storage of an avulsed tooth prior to replantation: a systematic review and meta-analysis. Dent Traumatol 2020;36:453-476.
PUBMED | CROSSREF