Laser Therapy for Treatment of Peri-Implant Diseases: An American Academy of Periodontology Best Evidence Review

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Background: Peri-implant diseases are prevalent, with numerous therapies studied in an attempt to combat this condition. The present review aims to systematically evaluate the effectiveness of laser therapy with non-surgical or surgical therapy in managing peri-implant diseases.

Methods: An electronic search of three databases and a hand search of peer-reviewed journals for relevant articles published (in English) from January 1980 to June 2016 were performed. Human clinical trials of ≥10 patients with peri-implant diseases, treated with surgical or non-surgical approaches and laser therapy, and a follow-up period of ≥6 months, were included. Random-effects meta-analyses were performed to analyze weighted mean difference (WMD) and confidence interval for the recorded variables according to PRISMA guidelines. Risk of bias assessment was also performed for randomized controlled trials included.

Results: From 22 articles selected, 11 were included in the meta-analyses. The outcomes of using lasers as a monotherapy could not be evaluated since no controlled studies were identified. Therefore, all reported results were the outcomes of applying lasers as an adjunct to surgical/non-surgical treatment. For the non-surgical approach, WMD of probing depth (PD), clinical attachment level (CAL), bleeding on probing (BOP), plaque index (PI), marginal bone level (MBL) and recession (REC) was 0.15 mm ($P = 0.50$), –0.10 mm ($P = 0.32$), 21.08% ($P = 0.02$), –0.07 ($P = 0.002$), –0.22 mm ($P = 0.04$) and –0.11 mm ($P = 0.34$), respectively. For the surgical approach with a long-term follow up, WMD of PD, CAL, BOP, and PI was 0.45 mm ($P = 0.11$), 0.22 mm ($P = 0.56$), 7.26% ($P = 0.76$) and –0.09 ($P = 0.84$), respectively.

Conclusions: Current evidence shows laser therapy in combination with surgical/non-surgical therapy provided minimal benefit in PD reduction, CAL gain, amount of REC improvement, and PI reduction in the treatment of peri-implant diseases. Lasers when used as an adjunct to non-surgical therapy might result in more BOP reduction in the short term. However, current evidence allowed for analysis of only Er:YAG, CO_2, and diode lasers. Studies on others failed to have controlled evidence supporting their evaluation. *J Periodontol 2018;89:000-000.*

KEY WORDS

Decontamination; dental implants; peri-implantitis; lasers; meta-analyses; systematic review.

Laser, an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation, was introduced in periodontics in the 1990s1-3 as a tool in diagnostics, surgeries, and physiologic studies.4 It is a device that emits light coherently into a small, intense, and nearly non-divergent beam with sufficient energy to cut through hard and soft tissues. The effect of a laser depends on the energy emitted and absorption by the target tissue. Basically, this energy represents a monochromatic light that is collimated into a focused beam interacting with the targeted tissue by being scattered, transmitted, absorbed, or reflected (see supplementary Figure 1 in online *Journal of Periodontology*)[ID]SUPFIG1[/ID]. The power of the energy could result in effects such as warming, coagulation, or vaporization of the tissues, based on different energy levels.[4] Therefore, lasers have myriad applications in periodontics and implant dentistry, which includes non-surgical and surgical periodontal therapy,5,6 gingivectomy and crown-lengthening procedures,7,8 as well as decontamination of implants with peri-implantitis.9

Given the increased use of dental implants in oral reconstructions, it is no surprise that recent epidemiologic research demonstrated mean prevalence rates of 43% and 22% for peri-implant mucositis and peri-implantitis, respectively.10 Likewise, there is an increase in the number of studies conducted seeking an effective and predictable therapy for peri-implant diseases. It was shown that peri-implant mucositis could be effectively treated by mechanical non-surgical therapy,11 and peri-implantitis generally requires surgical interventions.12,13 Consequently, a variety of surgical approaches, such as access flap debridement, resective and regenerative procedures, implantoplasty, and lasers for implant surface decontamination, have been proposed.14

With only limited evidence in specific scenarios, the employment of lasers around implants has been proven effective in different clinical therapies, such as non-surgical treatment15 and the combination of lasers and surgical treatment;16,17 however, conflicting results have been reported when lasers were used as a method for implant surface detoxification.16-18 A recent review concluded that laser therapy provided identical outcomes as other surface detoxification methods with regard to probing depth (PD) reduction, clinical attachment level (CAL) gain, and radiographic bone fill.19 The tremendous heterogeneity in treatment outcomes after the application of lasers for peri-implant diseases could be attributed to three main factors: 1) the multifactorial etiology of peri-implant infections, including host- and implant- related factors, could play a major role in treatment outcomes;20-23 2) the wide range of lasers investigated had different properties and settings (i.e., wavelength, power, waveform, pulse duration, energy/pulse, density of the energy, duration of the exposure, angulation of the energy toward the targeted tissue, peak power of the pulse, and the properties of tissue),4 all of which could strongly influence the treatment outcomes; and 3) the frequency of use might have an impact on treatment outcomes as several studies demonstrated positive results with repeated application of lasers to peri-implant defects.[15]

Despite the increasing number of investigations conducted using lasers for implant surface detoxification, significant heterogeneity and controversy still exist. Hence, the aim of this systematic review and meta-analyses is to evaluate the potential of lasers in the detoxification and treatment of peri-implant diseases.

MATERIALS AND METHODS

Population, Intervention, Comparison, Outcome (PICO) Question[24]

The focused question of this systematic review was: "Do lasers used alone or as adjuncts provide better treatment and patient outcomes in the management of peri-implant mucositis or peri-implantitis"? The population selected comprised individuals with peri-implant mucositis or peri-implantitis. The intervention investigated was the use of lasers alone or as adjuncts in surgical/non-surgical therapies. The selected outcomes to be compared between individuals treated with laser and those treated without were changes in: 1) PD, 2) CAL, 3) percentage of bleeding on probing (BOP), 4) plaque index (PI), 5) recession (REC), and 6) marginal bone level (MBL).

Selection Criteria

Prospective and retrospective human case series (CS), controlled clinical trials (CCTs), or randomized controlled clinical trials (RCTs) published (in English) from January 1980 to June 2016 were screened. Inclusion criteria were: 1) had ≥10 patients diagnosed with peri-implant mucositis or peri-implantitis and treated with lasers surgically or non-surgically; 2) had a follow-up period of ≥6 months; and 3) reported outcomes of one of the clinical parameters (PD, CAL, BOP, PI, REC, or MBL) after the therapy. Exclusion criteria were studies published as: 1) editorials; 2) letters or comments and non-English citations; 3) animal/in vitro studies; 4) review articles; and 5) case reports/series with <10 patients.

Screening Process

Two independent examiners (G-HL and FSLA) conducted the literature search using three databases (Ovid MEDLINE, EMBASE, and Dentistry and Oral Sciences Source). The search terms used, where mh represented the MeSH terms and tiab represented title and/or abstract, in MEDLINE/PubMed were: ("peri-implantitis"[mh] OR "peri-implant mucositis"[tiab] OR "peri-implant"[tiab] OR "peri-implants"[tiab] OR "peri-implantitis"[tiab] OR peri-implant[tiab] OR periimplants[tiab] OR periimplantitis[tiab]) AND ("laser therapy"[mh] OR "lasers, solid-state"[mh] OR laser[tiab] OR lasers[tiab]) AND English[la] NOT (letter[pt] OR comment[pt] OR editorial[pt]) The search terms used in EMBASE were: 'periimplantitis'/exp OR 'peri—implant':ab,ti OR 'peri—implants':ab,ti OR 'peri-implantitis':ab,ti OR peri-implant*:ab,ti AND ('laser'/exp OR 'solid state laser'/exp OR laser*:ab,ti) AND [english]/lim NOT ([animals]/lim NOT [humans]/lim) NOT ('letter'/exp OR 'editorial'/exp OR note:it OR erratum:it), and the search terms used in Dentistry and Oral Sciences Source were: (DE "PERI–-implantitis" OR TI "peri–-implant*" OR AB "peri–-implant*") AND (DE "Lasers" OR TI "Laser*" OR AB "Laser*")

A hand search was also performed for all offline journals (January 1980 to June 2016). Furthermore, a search in the references of included papers as well as the related systematic reviews was conducted for publications not electronically identified. The two reviewers (G-HL and FSLA) examined the pre-identified articles in full text, and their eligibility for this review was confirmed after discussion. The level of agreement between reviewers regarding study inclusion was calculated with κ statistics.

Statistical Analyses

Two reviewers (G-HL and FSLA) independently extracted data from papers that met inclusion criteria. Any disagreements were reconciled after discussion with a third reviewer (H-LW). Demographics, such as study design, sample size, numbers of implants, follow-up period, treatment outcome measurements, and study conclusion, were extracted and recorded for each selected study. Authors of the selected studies were contacted if additional information regarding the study was needed for the review and meta-analyses.

The primary outcome was PD reduction, and the secondary outcome was changes in recorded peri-implant parameters. The pooled weighted mean difference (WMD) and the 95% confidence interval (CI) of each variable were estimated using a computer program.[‡] Random effects meta-analyses of the selected studies were applied to minimize bias caused by methodologic differences among studies. Forest plots were generated to represent WMD and 95% CI in primary and secondary outcomes for all included studies using number of dental implants as the unit of analysis. Heterogeneity was assessed with χ^2 test and I^2 test, which ranged between 0% and 100% with the lower values representing less heterogeneity. If a study presented more than one test/control arm, the outcomes of each test/control group were combined. The reporting of these meta-analyses adhered to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) statement.25

Risk of Bias Assessment

Criteria used to assess the quality of the selected RCTs were modified from the RCTs checklist of the Cochrane Center26 and the CONSORT statement,27 which provided guidelines for the following parameters: 1) sequence generation; 2) allocation concealment method; 3) masking of examiner; 4) adequate handling of incomplete outcome data; and 5) absence of selective outcome reporting. The degree of bias was categorized as low risk (if all criteria were met), moderate risk (when only one criterion was missing), or high risk (if two or more criteria were missing). Two reviewers (G-HL and FSLA) assessed all included articles independently (see supplementary Table 1 in online *Journal of Periodontology*).[ID]SUPPTBL1[/ID]

Level of Evidence Assessment

The level of currently available evidence for lasers in treatment of peri-implant diseases was examined. The authors categorized the evidence level based on the following criteria: 1) "no evidence" (represents no RCTs or CCTs were identified to warrant the treatment benefit); 2) "limited evidence" (represents ≤3 RCTs or CCTs were identified); and 3) "some evidence" (represents >3 RCTs or CCTs were identified) (see supplementary Table 2 in online *Journal of Periodontology*)[ID]SUPPTBL2[/ID].

RESULTS

The screening process is shown in [ID]FIG1[/ID]Figure 1. Electronic and hand searches yielded 237 articles, of which 27 were selected for full-text evaluation after screening of titles and abstracts. Five articles28-32 were then further excluded due to the following: 1) being an in vitro study;31 2) use of a light-emitting diode source instead of laser;30,32 and 3) no clinical data reported.28,29 Twenty-two total articles9,15-18,33-49 were included in this systematic review. The main features and conclusions of the included studies are summarized in [ID]TBL1[/ID]Table 1 (non-surgical) and [ID]TBL2[/ID]Table 2 (surgical). Eleven papers (nine RCTs9,16,18,34,37,39,41,43,45 and two CCTs48,49) that met the inclusion criteria were included for meta-analyses. It is worth noting that currently no controlled studies are identified offering evidence of lasers used as a monotherapy in the treatment of peri-implantitis. The κ value for inter-reviewer agreement for potentially relevant articles was 0.93 (titles and abstracts) and 0.97 (full-text articles), indicating an "almost perfect" agreement between the two reviewers.50

Features of the Included Studies

Among the 22 human clinical trials, lasers were used as an adjunct to non-surgical interventions in 13 studies (Table 1).15,34-37,40-43,45,47-49 In the other nine studies,9,16-18,33,38,39,44,46 lasers were used with a surgical approach (Table 2). Although the current review aims to investigate the effect of adjunctive laser treatment on clinical outcomes of peri-implant diseases, most of the included articles focused on peri-implantitis, and only three studies47-49 used lasers as an adjunct in the treatment of peri-implant mucositis. Seven studies9,16-18,33,38,44 introduced guided bone regeneration (GBR) procedures as part of surgical treatment with either non-resorbable16,33 or absorbable9,17,18,38,44 membranes. Most of the treated implants in the selected studies were rough-surfaced implants,9,15-18,33-35,38-49 whereas smooth-surfaced implants were more commonly found in the non-surgical laser-treated approach.36,37 Among the selected studies that examined a surgical treatment modality, the diode laser was used in three studies,33,39,46 the carbon dioxide (CO_2) laser in two studies,16,17 and the erbium:yttrium-aluminum-garnet (Er:YAG) laser in four studies.9,18,38,44 For studies that used a non-surgical treatment approach, the diode laser was used in eight studies,15,40-43,45,48,49 and the Er:YAG laser was introduced in five studies.34-37,47 The selected articles generally included mechanical hand curettage with plastic, titanium, or carbon fiber curets. However, air abrasives,16,36,37,40,41,43 chlorhexidine rinse,9,34 or locally delivered antibiotics41,43 were applied in some studies. The follow-up period ranged from 618,39,44,46 to 6016 months in studies that used the surgical approach and 6 to 12 months in those with the non-surgical approach.15,34-37,40-43,45,47-49

Meta-analyses conducted in the current study only include CCTs and RCTs with data comparing the clinical parameters between groups with and without adjunctive laser treatment. For non-surgical treatment, all included studies had a follow-up period of 6 to 12 months; therefore, only short-term clinical outcomes could be analyzed. For surgical groups, two studies9,16 reported data after a 48-month follow-up period; therefore, short-term and long-term outcomes were analyzed separately. Two articles by Schwarz et al.[9,38] were follow-up studies of an early study.[18] Similarly, Renvert et al.[37] and Persson et al.[36] retrieved data from the same population. Therefore, repeated data were not included in meta-analyses. Most studies[9,15-18,34-49] reported a PD and BOP reduction with CAL gain when defects were treated surgically or non-surgically. Higher mean PD reduction was generally achieved in the group augmented with bone grafts and membranes. Slight MBL loss was reported in some non-surgical treatment groups using lasers.[37,45,49] When compared with mechanical debridement and antiseptics in combination with a surgical approach, the addition of laser treatment showed slight-to-no benefit in PD/BOP reduction and CAL gain. In the non-surgical treatment group, the addition of lasers showed significant reduction of BOP compared with the non-laser treatment group. However, a slight but significant MBL loss was also detected in the laser treatment group.

Short-Term (≤12 months) Outcomes of Non-Surgical Treatment in Combination With Lasers

Of the included studies, six articles[34,37,41,43,45,49] were selected and pooled in the meta-analyses. These six studies presented a follow-up period of 6 to 12 months, of which four studies[41,43,45,49] used the diode laser and another two studies[34,37] used the Er:YAG laser.

A total of six articles[34,37,41,43,45,49] were pooled to evaluate PD reduction. The results presented WMD of 0.24 mm (95% CI = –0.38 to 0.85 mm, $P = 0.45$, four studies were included[41,43,45,49]), –0.07 mm (95% CI = –0.32 to 0.18 mm, $P = 0.57$, two studies were included[34,37]), and 0.15 mm (95% CI = –0.28 to 0.57 mm, $P = 0.50$) for diode laser, Er:YAG laser, and overall comparison, respectively. No statistical significance was found [ID]FIG2[/ID](Fig. 2A) for any of the comparison between groups. The comparisons presented a low heterogeneity for Er:YAG laser ($P = 0.59$) and high heterogeneity for diode laser ($P < 0.001$) and overall comparisons ($P < 0.001$).

In terms of CAL gain, three articles[34,41,43] were analyzed. The results presented WMD of –0.12 mm (95% CI = –0.33 to 0.09 mm, $P = 0.25$, two studies were included[41,43]), 0.10 mm (95% CI = –0.54 to 0.74 mm, $P = 0.76$, only one study was included[34]), and –0.10 mm (95% CI = –0.30 to 0.10 mm, $P = 0.32$) for diode laser, Er:YAG laser, and overall comparison, respectively. No statistical significance was found (Fig. 2B) for any comparisons between groups. The comparisons presented low heterogeneity for diode laser ($P = 0.35$) and overall comparisons ($P = 0.52$).

Pertaining to BOP reduction, two articles were analyzed.[34,48] The results presented WMD of 12.70% (95% CI = 10.71% to 14.69%, $P < 0.001$, one study[48]), 30.56% (95% CI = 21.68% to 39.44%, $P < 0.001$, one study[34]), and 21.08% (95% CI = 3.61% to 38.55%, $P = 0.02$) for diode laser, Er:YAG laser, and overall comparison, respectively. Statistical significance was found, favoring laser treatment group (Fig. 2C). However, the comparison presented a high heterogeneity for overall comparison ($P = 0.001$).

Regarding PI reduction, three[34,41,43] articles were analyzed. The results presented WMD of –0.07 (95% CI = –0.12 to –0.03, $P = 0.002$, two studies included[41,43]), 0.00 (95% CI = –0.25 to 0.25, $P > 0.99$, one study[34]), and –0.07 (95% CI = –0.12 to –0.03, $P = 0.002$) for diode laser, Er:YAG laser, and overall comparisons, respectively. Statistical significance was found for diode laser and overall comparisons, favoring non-laser treatment group (Fig.

2D). The comparisons presented a low heterogeneity for diode laser (P = 0.41) and overall comparison (P = 0.60).

The outcome of MBL was reported in three articles.[37,45,48] The results presented WMD of −0.23 mm (95% CI = −0.50 to 0.04 mm, P = 0.10, two studies were included[45,48]), −0.20 mm (95% CI = −0.53 to 0.13 mm, P = 0.24, one study[37]), and −0.22 mm (95% CI = −0.43 to −0.01, P = 0.04) for diode laser, Er:YAG laser, and overall comparisons, respectively. Statistical significance was found for diode laser and overall comparisons, favoring control group (Fig. 2E). The comparisons presented a high heterogeneity for diode laser (P = 0.003) and overall comparison (P = 0.01).

In terms of REC, three articles were analyzed.[34,41,43] The results presented WMD of −0.17 mm (95% CI = −0.44 to 0.11 mm, P = 0.24, two studies were included[41,43]), 0.00 mm (95% CI = −0.37 to 0.37 mm, P >0.99, one study[34]), and −0.11 mm (95% CI = −0.33 to 0.11 mm, P = 0.34) for diode laser, Er:YAG laser, and overall comparison, respectively. No statistical significance was found (Fig. 2F) for any of the comparison between groups. The comparisons presented a low heterogeneity for diode laser (P = 0.62) and overall comparisons (P = 0.69).

Short-Term (≤12 months) Outcomes of Surgical Treatment in Combination With Lasers

Of the included studies, two articles[18,39] were selected and pooled in meta-analyses. Both articles reported treatment outcomes after a 6-month follow-up.

For PD reduction, an overall WMD of 0.08 mm (95% CI = −1.28 to 1.44 mm) between laser treatment group and conventional treatment group with no statistical significance (P = 0.91) was found [ID]FIG3[/ID](Fig. 3A). The comparisons presented a high heterogeneity among selected studies (P value for χ^2 test = 0.006 and I^2 test = 87%).

In terms of CAL gain, an overall WMD of −0.03 mm (95% CI = −1.13 to 1.07 mm), with no statistical significance (P = 0.96) was found (Fig. 3B). The comparisons presented a high heterogeneity among selected studies (P value for χ^2 test= 0.02 and I^2 test = 83%).

An overall WMD of 9.88% (95% CI = –26.46% to 46.21%), with no statistical significance (P = 0.59) with regard to BOP reduction was found (Fig. 3C). The comparisons presented a moderate-to-high heterogeneity among selected studies (P value for χ^2 test = 0.05 and I^2 test = 73%).

Since there was only one comparative study[18] reporting differences in PI and REC between test and control groups, the meta-analyses could not be performed. Based on this article, mean difference was −0.10 (95% CI = −0.47 to 0.27) for PI and 0.0 mm (95% CI = −0.17 to 0.17 mm) for REC, with no detectable statistical significance (P = 0.60 for PI; P >0.99 for REC) between groups. In addition, no short-term studies reported outcomes of MBL change; therefore, short-term MBL change between groups could not be evaluated.

Long-Term (≥48 months) Outcomes of Surgical Treatment in Combination With Lasers

Among the included studies, two articles[9,16] were selected and pooled in the meta-analyses to evaluate the long-term treatment outcomes. One study[9] was a 4-year follow-up of a previous study.[18] Another study, by Deppe et al.,[16] reported treatment outcomes after a 60-month follow-up.

An overall WMD of 0.45 mm (95% CI = –0.10 to 1.00 mm) between laser treatment group and conventional treatment group, with no statistical significance ($P = 0.11$) was found for PD reduction [ID]FIG4[/ID](Fig. 4A). The comparisons presented a low heterogeneity among selected studies (P value for χ^2 test = 0.64 and I^2 test = 0%).

In terms of CAL gain, an overall WMD of 0.22 mm (95% CI = –0.52 to 0.95 mm), with no statistical significance ($P = 0.56$) was found (Fig. 4B). The comparisons presented a low heterogeneity among selected studies (P value for χ^2 test = 0.52 and I^2 test = 0%).

Pertaining to BOP reduction, an overall WMD of 7.26% (95% CI = –38.77% to 53.29%), with no statistical significance ($P = 0.76$) was found (Fig. 4C). The comparisons presented a high heterogeneity among selected studies (P value for χ^2 test = 0.03 and I^2 test = 80%).

An overall WMD of –0.09 (95% CI = –0.95 to 0.77), with no statistical significance ($P = 0.84$) was found for PI reduction (Fig. 4D). The comparisons presented a moderate heterogeneity among selected studies (P value for χ^2 test = 0.06 and I^2 test = 71%).

Only one comparative study reported MBL[16] differences between test and control groups, likewise for differences in REC.[9] As a result, the meta-analysis could not be performed. Based on these studies, mean difference of MBL and REC was 0.64 mm (95% CI = –0.24 to 1.52 mm) and 0.20 mm (95% CI = –0.35 to 0.75 mm), respectively, with no statistical significance ($P = 0.15$ for MBL and $P = 0.47$ for REC) detected between groups.

Risk of Bias Assessment

The results of the risk of bias assessment for included RCTs are summarized in supplementary Table 1 in the online *Journal of Periodontology*. Four studies[34,36,37,41] had low risk of bias, three studies[18,39,46] had moderate risk of bias, and three studies[9,43,45] had high risk of bias.

Level of Evidence Assessment

The results of level of evidence assessment are reported in supplementary Table 2 in the online *Journal of Periodontology*. No evidence is currently available to support the use of lasers in treatment of peri-implant mucositis. As for non-surgical treatment of peri-implantitis, some evidence presented controversial clinical benefits of adjunct laser treatment in the short term, but no evidence was found to support the long-term benefits. As for surgical treatment of peri-implantitis, limited evidence presented controversial short-term clinical benefits and no long-term benefits.

DISCUSSION

While previous studies[51,52] suggested that peri-implant mucositis might be successfully treated if detected early and when combined with non-surgical treatment, a complete resolution of peri-implant inflammation was not commonly obtained.[53] Therefore, the current review aims to identify the potential benefit of adjunctive laser therapy in the treatment of peri-implant mucositis and peri-implantitis. However, among the selected 22 human clinical trials, only three studies47-49 included patients with peri-implant mucositis; other studies only selected patients with peri-implantitis. In a study by Schwarz et al.,47 carbon curets and chlorhexidine rinse for surface detoxification were used to treat peri-implant mucositis, while Er:YAG laser was used to treat peri-implantitis. Although both groups achieved short-term significant clinical improvements, a complete disease resolution was not achieved in the majority of the study patients. Another two studies48,49 compared the effect of mechanical debridement with or without adjunctive diode laser treatment on clinical outcomes of peri-implant diseases and reported significant reduction of PD and BOP if the laser was used. However, since the disease status (peri-implant mucositis or peri-implantitis) of the participants was not clearly demarcated in the analysis of the treatment outcomes, the evidence supporting the use of lasers to treat peri-implant mucositis was limited. Currently the efficacy of non-surgical treatment of peri-implant mucositis with or without using lasers could not be warranted, and more RCTs should be conducted in the future to investigate this topic.

Pertaining to treatment of peri-implantitis, the current review and meta-analyses failed to detect significant PD reduction and CAL gain when lasers were used together with non-surgical and surgical therapies. This result was consistent with previously published systematic reviews.19,54 However, the current review identified two recent articles39,46 that introduced the diode laser in the surgical management of peri-implantitis. While both studies demonstrated promising outcomes in PD reduction and CAL gain when the laser was used versus mechanical debridement only, the WMD presented less than 1 mm for both parameters. Therefore, the adjunctive use of diode laser in surgical treatment of peri-implantitis appeared to be effective; however, its efficacy still required further investigations.

When considering the benefit of GBR procedures in treating peri-implant defects, most of the defects that had GBR achieved better outcomes in terms of PD reduction, CAL gain, and MBL gain.9,16-18,33,38,44 However, an addition of lasers to GBR procedures did not present further improvement to the peri-implant parameters.9,16,18,38 Therefore, GBR procedures should be considered as a standard treatment modality irrespective of the use of lasers when dealing with intrabony peri-implant defects.44

Peri-implant tissue recession after surgical therapy with and without adjunctive laser treatment was only reported from a series of publications by Schwarz et al.9,18,38 In their studies, the same population was followed up to 48 months, and slight recession, ranging from 0.1 to 0.3 mm, was observed. For the intervention, no significant change in soft tissue level (ranging from 0.03 to 0.3 mm) was observed in studies34,41,43 that evaluated non-surgical therapy with and without laser. Therefore, the current evidence revealed that adjunctive laser treatment combined with surgical/non-surgical therapies did not interfere with peri-implant soft tissue levels.

Conflicting data on BOP reduction was reported in selected studies. 9,18,34,38,39,46,48 Some studies reported significant BOP reduction when lasers were introduced.34,39,48 On the contrary, other studies9,18,38,46 did not find significant BOP reduction as compared with conventional treatment. It appeared that the adjunctive use of lasers with non-surgical therapy might decrease BOP after a short follow-up period of 6 to 12 months. This could be explained by the coagulation or vaporization of the tissues after laser treatment, and reflects the truth that a long-term control of tissue inflammation might be related to maintenance protocol instead of active treatment. However, when adjunctive lasers were used in surgical treatment, there was no significant BOP reduction detected.9,16 Interestingly, previous studies have reported a higher percentage of BOP around dental implants despite lower plaque scores and fewer signs of inflammation.21,55 Also, higher sensitivity of probing around dental implants compared with probing around teeth has been reported;56 therefore, clinicians should be aware that the presence of BOP might not accurately represent the inflammatory status of the peri-implant tissues. Also, absence of BOP has been reported as a good indicator of healthy peri-implant mucosa, but presence of BOP might have limited diagnostic value.57 As such, clinicians should evaluate this parameter cautiously and not apply the presence of BOP as a criterion of treatment outcomes.

The results of this meta-analysis showed no additional benefit in PI reduction when lasers were used as an adjunct to conventional intervention. Interestingly most data reported a minimal difference in PI (a change of <1) between baseline and the final follow-up appointment in groups with and without laser treatment. Therefore, it could be assumed that the outcome of PI reduction might not be significantly related to treatment modalities. Other factors, such as maintenance protocol58 or the use of locally delivered antibiotics,41,43 might have a larger impact on PI reduction.

Most studies that evaluated surgical interventions used GBR in the treatment of both test and control groups.9,16-18,33,38,44 Therefore, MBL could not be accurately evaluated since this difference might not be related to the adjunctive use of laser therapy. When performing non-surgical treatment, a statistically significant MBL loss was detected (-0.22 mm with 95% CI = -0.43 to -0.01, $P = 0.04$) in the laser-treated group compared with the control group. This might be a result of uncontrolled temperature increase in the laser-treated area, thus further jeopardizing the healing outcomes.45,59 However, when interpreting this result, clinicians should be aware that only three studies[37,45,48] were pooled in the meta-analyses and this difference was minimal in terms of clinical significance. Nonetheless, after repeated application of a diode laser, Mettraux et al.15 reported sound improvement in clinical parameters for implants affected by peri-implantitis. Results from this study opened a new area of future research to investigate the need for repeated laser applications to decontaminate an implant surface.

Comparisons of bacterial profile between treatment with and without adjunctive laser therapy were recorded in six studies.28,29,36 39,43,45 Among these six studies, three studies28,29,39 introduced surgical approaches, while the remaining three studies had non-surgical treatment.36,43,45 Bach et al.,28 in an early study, reported that the elimination of certain pathogenic bacteria with diode laser could be maintained at the 60-month follow-up in 10 of 15 patients. Moreover, significant reduction of black-pigmented, Gram-negative anaerobic bacteria was noted throughout the study period. Similarly, Dörtbudak et al.29 used a diode laser in combination with surgical treatment to evaluate reduction of bacteria counts in patients with peri-implantitis. The results of their study showed that the combined treatment significantly reduced the bacterial counts of *Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis,* and *Prevotella intermedia*. However, this study lacked a control group, and complete elimination of bacteria was never achieved. Recently, Bombeccari et al.39 concluded that a diode laser, when used as an adjunct to surgical treatment, was able to reduce the bacterial biofilm by 95.2% colony-forming units (CFUs) per milliliter compared to 80.85% CFU reduction in conventional treatment group.

As for non-surgical intervention, all three studies[37,43,45] that introduced laser therapy as an adjunct reported no additional benefit on the peri-implant microbiota compared with conventional mechanical debridement after a 6- to 12-month follow-up period. Interestingly, it has been reported that results of microbiologic testing are often inconsistent due to different laboratory processing;[60,61] thus this information should always be interpreted cautiously. To date, there are very few clinical trials that have assessed the efficacy of various laser treatments on microbiologic outcomes; therefore, a firm conclusion cannot be drawn.

There were a number of limitations in the current systematic review and meta-analyses: 1) only 11 papers with comparable data were included in the meta-analyses; 2) a few analyses presented with high heterogeneity (this heterogeneity was related to the presence of confounding factors within and among the selected studies, for example, different study designs, follow-up periods, various lasers settings, etc.); 3) owing to the limited available data, patient-centered outcome measures, cost-effectiveness of lasers, and microbiologic data were not analyzed in the current review; 4) the systematic review only included studies written in English, which could result in a selection bias; 5) because peri-implant diseases are multifactorial and affected by numerous local and systemic factors, further investigations should evaluate the influence of both implant- and host-related factors as they both play a major role in treatment outcomes; and 6) the various definitions of peri-implant diseases as well as different measurement methods of clinical parameters might also influence the presented results. Moreover, the main parameter used for evaluation of disease status (PD) is subject to multiple variables that might affect its accuracy.

CONCLUSIONS

Current evidence allowed for analysis of only Er:YAG, CO_2, and diode lasers. Studies on others failed to have controlled evidence to support their evaluation. Since the types of lasers analyzed have different modes of action, the limited number of included studies and patients/implants evaluated makes it difficult to warrant their therapeutic values. Data on adjunctive laser treatment for peri-implant mucositis are scarce. Therefore, future clinical trials are needed to evaluate the potential benefit of this approach. Based on the results of meta-analyses, when treating peri-implantitis surgically, no differences in PD reduction, CAL gain, amount of REC, and PI reduction were found between groups with and without adjunctive laser treatment. However, controversial results have been reported in the literature. Also based on the results of meta-analyses, when treating peri-implantitis non-surgically, adjunctive laser treatment might result in more BOP reduction in the short term. However, no long-term data were available to warrant this benefit. Limited evidence showed that non-surgical treatment with adjunctive laser therapy might result in slightly more MBL loss compared with conventional treatment and also showed a potential reduction in dark pigmented, gram-negative anaerobic bacteria when applying adjunctive diode laser therapy to surgical treatment of peri-implantitis. However, this benefit was not detected in non-surgical treatment with adjunctive laser therapy.

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Figure 1. Flowchart illustrating the publication selection process.

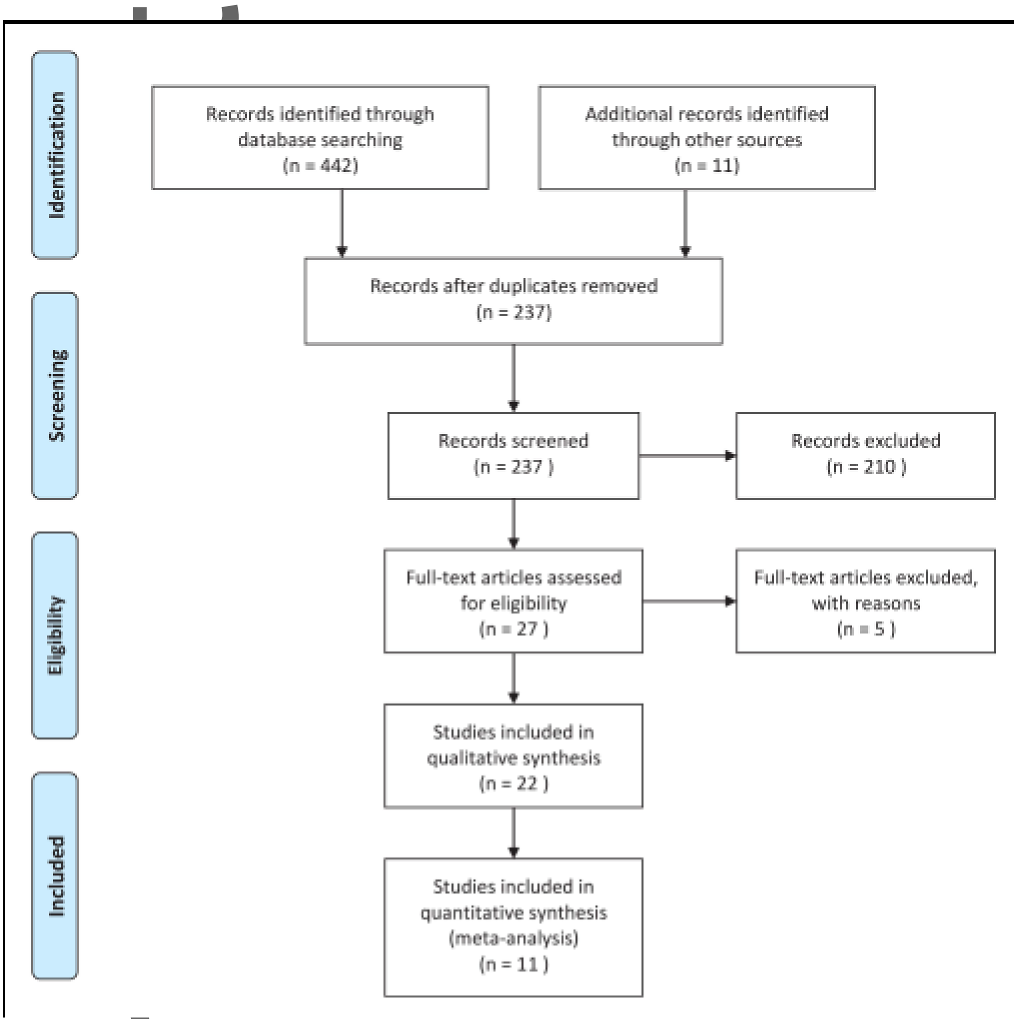

Figure 2.

Meta-analyses for the comparison of clinical parameters in non-surgical approach between groups with adjunctive laser therapy (test) and without laser therapy (control) among selected studies. **A)** Comparison of PD reduction; **B)** comparison of CAL gain; **C)** comparison of BOP reduction; **D)** comparison of PI; **E)** comparison of MBL loss; **F)** comparison of REC increase. IV = independent variable.

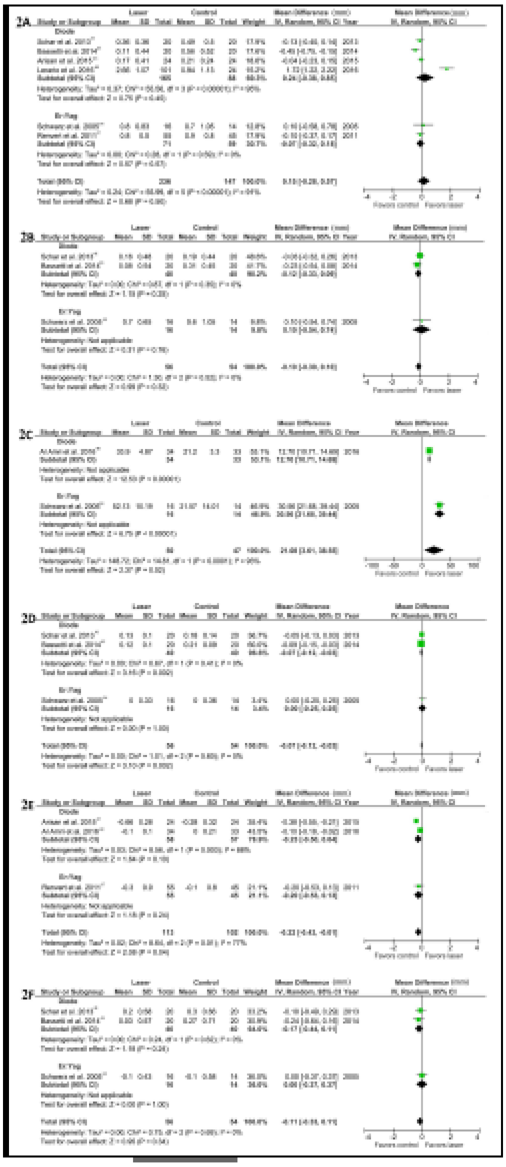

Figure 3.

Meta-analyses for the comparison of clinical parameters in surgical approach between groups with adjunctive laser therapy (test) and without laser therapy (control) among selected studies after a short follow-up period of 6 to 12 months. **A)** comparison of PD reduction; **B)** comparison of CAL gain; **C)** comparison of BOP reduction. IV = independent variable.

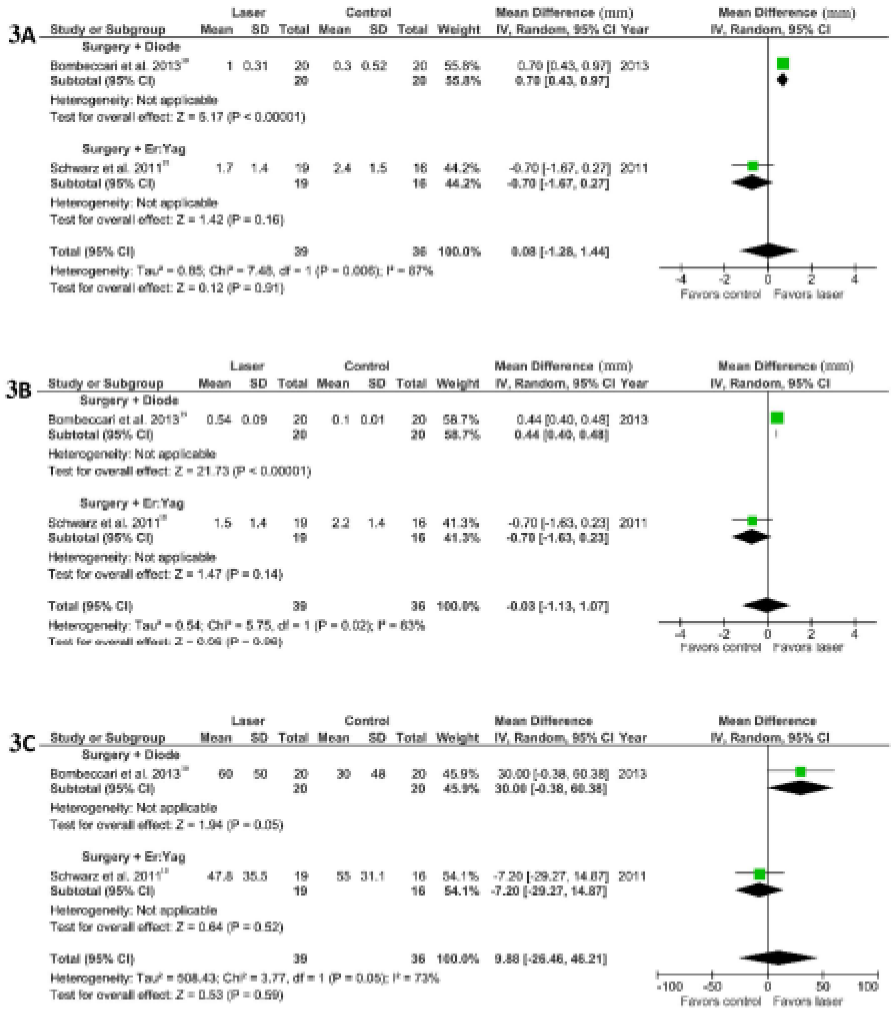

Figure 4.

Meta-analyses for the comparison of clinical parameters in surgical approach between groups with adjunctive laser therapy (test) and without laser therapy (control) among selected studies after a long-term follow-up period of 48 to 60 months. **A)** comparison of PD reduction; **B)** comparison of CAL gain; **C)** comparison of BOP reduction; **D)** comparison of PI. IV = independent variable.

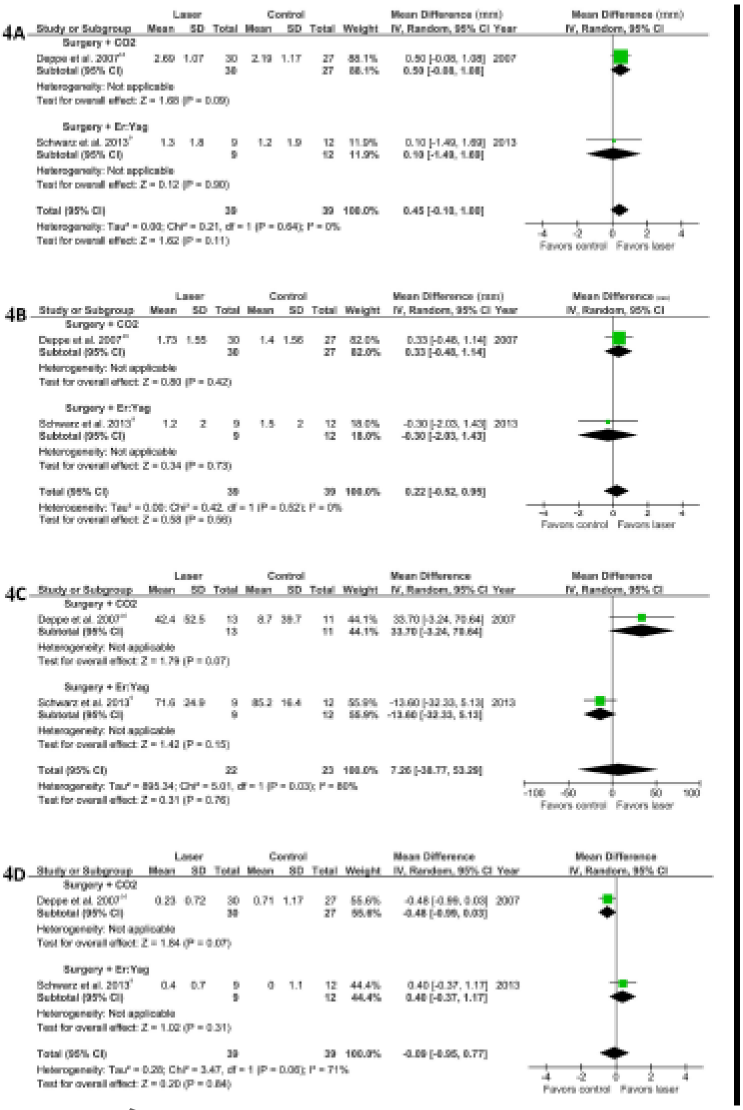
4A
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Table 1.

Features of the Included Articles Using a Non-Surgical Approach

Author/Year	Study Design	Groups	Type	Laser Settings	Patients (n)	Implants (n)	Follow-up (months)	Diagnosis Mucositis/Peri-Implantitis	Treatment Outcomes (difference; mean ± SD) PD (mm)	CAL (mm)	MBL (mm)	BOP (%)	PI	REC (mm)	Conclusions
Schwarz et al. 2005[34]*	RCT	T: Laser C: MI (plastic curets + CHX)	Er:YAG	2,940 nm, 12.7 J/cm^2	T: 10 C: 10	T: 16 C: 14	6	Peri-implantitis	T: 0.8 ± 0.83 C: 0.7 ± 1.05	T: 0.7 ± 0.65 C: 0.6 ± 1.05		T: 52.13 ± 10.19 C: 21.57 ± 14.01	T: 0 ± 0.33 C: 0 ± 0.36	T: –0.1 ± 0.43 C: –0.1 ± 0.58 (increase)	Laser group resulted in a statistically significant higher reduction of BOP than control.
Schwarz et al. 2006[35]	CS	Laser	Er:YAG	2,940 nm, 12.7 J/cm^2	n = 12 (data of only eight patients extracted)	n = 12 (data of only eight implants extracted)	24 (only 6-month data retrieved)	Peri-implantitis	1.86 ± 0.61	0.87 ± 0.71		68.63 ± 12.85	0.13 ± 0.16	0.24 ± 0.39 (increase)	Single course of non-surgical treatment of peri-implantitis using Er:YAG laser was not sufficient for the maintenance of failing implants.
Persson et al. 2011[36]	RCT	T: Laser C: Air-abrasive	Er:YAG	100 mJ/pulse and 10 Hz (12.7 J/cm^2)	T: 21 C: 21	T: 55 C: 45	6	Peri-implantitis	T: 0.9 ± 0.8 C: 0.8 ± 0.5						Both methods failed to reduce bacterial counts. Clinical improvements were limited.
Renvert et al. 2011[37]*	RCT	T: Laser C: Air-abrasive	Er:YAG	100 mJ/pulse and 10 Hz (12.7 J/cm^2)	T: 21 C: 21	T: 55 C: 45	6	Peri-implantitis	T: 0.8 ± 0.5 C: 0.9 ± 0.8		T: –0.3 ± 0.9 C: –0.1 ± 0.8				Clinical improvement was similar between treatments using an Er:YAG

															laser or air-abrasive for debridement.
Deppe et al. 2013[40]	Pilot	Air-abrasive + laser 1: moderate bone loss 2: severe bone loss	Diode	660 nm, 100 mW with 60 mW/cm^2	16	18	6	Peri-implantitis	1: 0.4 ± 0.63 2: –0.7 ± 0.91 (increased PD)	1: 1.4 ± 0.97 2: –0.2 ± 0.98 (CAL loss)	1: –0.3 ± 0.75 2: 1.9 ± 0.81			1: 0.2 ± 0.43 2: 0.7 ± 1.29	Non-surgical diode laser treatment could stop bone resorption in moderate peri-implant defects but not in severe defects.
Schär et al. 2013[41]*	RCT	T: MI + air polishing + H_2O_2 + laser C: MI (titanium curets) + air polishing + minocycline	Diode	660 nm, 100 mW	T: 20 C: 20	T: 20 C: 20	6	Peri-implantitis	T: 0.36 ± 0.36 C: 0.49 ± 0.50	T: 0.16 ± 0.48 C: 0.19 ± 0.44		BOP-positive sites T: 4.03 ± 1.66 to 1.51 ± 1.41 C: 4.41 ± 1.47 to 2.10 ± 1.55	T: 0.13 ± 0.10 C: 0.18 ± 0.14	T: 0.20 ± 0.58 C: 0.30 ± 0.66	Both modalities had comparable reductions in inflammation and PD. Complete resolution of inflammation was not achieved with either therapy.

Table 1.

Features of the Included Articles Using a Non-Surgical Approach (continued)

Author/ Year	Study Design	Groups	Type	Laser Settings	Patients (n)	Implants (n)	Follow-up (months)	Diagnosis Mucositis/ Peri-Implantitis	Treatment Outcomes (difference; mean ± SD) PD (mm)	CAL (mm)	MBL (mm)	BOP (%)	PI	REC (mm)	Conclusions

Thierbach and Eger 2013[42]	CS	MI (plastic curets) + laser W: with pus WO: without pus	Diode	660 nm × 10 seconds	28	W: 17 WO: 33	7	Peri-implantitis	W: 0.43 ± 0.1 WO: 1.13 ± 0.17	W: 1.79 ± 0.36 WO: 1.3 ± 0.93		W: 85.91 ± 11.53 WO: 54.98 ± 28.19			Non-surgical treatment was effective in managing peri-implantitis without pus formation. Peri-implantitis with pus formation required a combination of surgical and regenerative procedures.
Bassetti et al. 2014[43]*	RCT	T: MI + air-polishing + laser C: MI (titanium curets) + air-polishing + minocycline	Diode	660 nm, 100 mW x 10 seconds	T: 20 C: 20	T: 20 C: 20	12	Peri-implantitis	T: 0.11 ± 0.44 C: 0.56 ± 0.52	T: 0.08 ± 0.54 C: 0.31 ± 0.45		T: 2.29 ± 0.97 C: 2.86 ± 0.0.88	T: 0.12 ± 0.10 C: 0.21 ± 0.09	T: 0.03 ± 0.57 C: 0.27 ± 0.71 (decreased)	Non-surgical mechanical debridement with adjunctive diode laser was equally effective in the reduction of inflammation as adjunctive delivery of minocycline microspheres.
Arısan et al. 2015[45]*	RCT	T: MI + laser C: MI (plastic curets)	Diode	810 nm, 1W pulsed mode with 3	10	T: 24 C: 24	6	Peri-implantitis	T: 0.17 ± 0.41 C: 0.21 ± 0.24		T: –0.66 ± 0.28 C: –0.	T: 100% to 95.8% C:100% to 100%	T: 91.7% to 54.2% C: 91.7		Diode laser did not yield any additional positive influence on the

Author/Year	Study Design	Groups	Type	Laser Settings	Patients (n)	Implants (n)	Follow-up (months)	Mucositis/Peri-Implantitis	PD (mm)	CAL (mm)	MBL (mm)	BOP (%)	PI	REC (mm)	Conclusions
				J/cm^2 × 1 minute							28 ± 0.32		% to 41.7 %		peri-implant healing compared with conventional scaling alone.
Mettraux et al. 2015[15]	CS	MI (carbon fiber curets) + laser	Diode	810 nm, 2.5 W, 50 Hz, 30s ×3	15	23	24	Peri-implantitis	Deepest PD buccal: 7.5 ± 2.6–3.6 ± 0.7 Deepest PD oral: 7.7 ± 2.1–3.8 ± 0.9			% of implants with ≥1 site with BOP: 100% to 43%			Non-surgical treatment of peri-implantitis with the use of diode laser resulted in significant clinical improvements for at least 2 years.
Schwarz et al. 2015[47]	CS	M: peri-implant mucositis, MI (carbon curets)+ CHX P: Peri-implantitis, laser	Er:YAG	2.94 × 1 minute, 12.7 J/cm^2	M: 17 P: 17	M: 24 P: 21	6	Both	P: 1.0 ± 0.9 M: 0.1 ± 0.6			P: 27.9 ± 18.5 M: 38.0 ± 23.1			Non-surgical treatment of peri-implant mucositis using MI + CHX or peri-implantitis using laser was associated with significant short-term clinical improvements.

Table 1.

Features of the Included Articles Using a Non-Surgical Approach (continued)

Author/ Year	Study Design	Groups	Type	Laser Settings	Patients (n)	Implants (n)	Follow-up (months)	Diagnosis	Treatment Outcomes (difference; mean ± SD)						Conclusions
								Mucositis/Peri-Implantitis	PD (mm)	CAL (mm)	MBL (mm)	BOP (%)	PI	REC (mm)	

Al Amri et al. 2016[48]*	CCT	T: MI + laser C: MI (ultrasonic scaler)	Diode	660 nm, 100 mW	T: 34 C: 33	T: 34 C: 33	12	Both	T: 15.8 ± 1.27 C: 15.2 ± 1.05		T: −0.1 ± 0.1 C: 0.0 ± 0.21	T: 33.9 ± 4.87 C: 21.2 ± 3.3			In patients with type 2 diabetes, MI with adjunctive diode laser treatment was more effective compared with MI alone.
Lerario et al. 2016[49]*	CCT	T: MI + laser C: MI (ultrasonic scaler and titanium curets)	Diode	810 nm, 1 W x 30 seconds	T:21 C:6	T: 101 C: 24	12	Both	T: 2.66 ± 1.07 C: 0.94 ± 1.13			T: 85.14 C: 27.78			Diode laser seemed to be a valuable tool in the treatment of mucositis and peri-implantitis. Significant PD and BOP reduction were observed.

T = test; C = control; MI = mechanical instrumentation; CHX = chlorhexidine rinse; Er:YAG = erbium:yttrium-aluminum-garnet.

*Article included in the meta-analyses.

Table 2.

Features of the Included Articles Using a Surgical Approach

Author/ Year	**Study Design**	**Groups**	**Type**	**Laser Settings**	**Patients (n)**	**Implants (n)**	**Follow-up (months)**	**Diagnosis**	**Treatment Outcomes (difference; mean ± SD)**						**Conclusions**
								Mucositis/ Peri-Implantitis	**PD (mm)**	**CAL (mm)**	**MBL (mm)**	**BOP (%)**	**PI**	**REC (mm)**	
Haas et al. 2000[33]	CS	GBR + laser	Diode	906 nm	17	24	mean 9.5	Peri-implantitis			2.0 ± 1.9				Photosensitizing treatment and GBR resulted in significant reduction of the peri-implant bone defect.

Deppe et al. 2007[16]*	CCT	T1: air abrasive + resective + laser T2: air abrasive + GBR + laser C1: air abrasive + resective/ GBR C2: air abrasive + GBR	CO_2	2.5W, 175 J/cm^2, 12 × 5 seconds	T1: 10 T2: 9 C1: 6 C2: 7	T1: 22 T2: 17 C1: 19 C2: 15	60	Peri-implantitis	T1: 2.3 ± 0.9 T2: 3.2 ± 1.1 C1: 1.9 ± 1.1 C2: 2.6 ± 1.2	T1: 0.6 ± 0.8 T2: 3.2 ± 0.9 C1: 0.3 ± 0.8 C2: 3.0 ± 0.8	T1: 0.6 ± 1.3 T2: 3.1 ± 0.9 C1: –0.1 ± 1.0 C2: 2.7 ± 0.9		T1: 0.4 ± 0.7 T2: 1.4 ± 0.7 C1: 1.0 ± 0.7 C2: 0.3 ± 0.9		CO_2 laser decontamination might be more efficacious than conventional decontamination in deep and narrow bony defects.
Romanos and Nentwig 2008[17]	CS	MI (titanium curets) + GBR + laser	CO_2	2.84 W, 1 minute	15	19	45	Peri-implantitis	3.52 ± 0.49			66.5 ± 59.9	0.03 ± 0.85		CO_2 laser decontamination in combination with GBR could be effective in treating peri-implantitis
Schwarz et al. 2011[18]*	RCT	T: MI + GBR + laser C: MI (plastic curets) + GBR	Er:YAG	11.4 J/cm^2, 10 pulses per second	T: 15 C: 15	T: 19 C: 16	6	Peri-implantitis	T: 1.7 ± 1.4 C: 2.4 ± 1.5	T: 1.5 ± 1.4 C: 2.2 ± 1.4		T: 47.8 ± 35.5 C: 55.0 ± 31.1	T: 0.4 ± 0.5 C: 0.5 ± 0.6	T: –0.2 ± 0.2 C: –0.2 ± 0.3	Laser treatment did not have significant benefit on surface decontamination.
Schwarz et al. 2012[38]	RCT	T: MI + GBR + laser C: MI (plastic curets) + GBR	Er:YAG	11.4 J/cm^2, 10 pulses per second	T: 10 C: 14	T: 10 C: 14	24	Peri-implantitis	T: 1.1 ± 2.2 C: 1.5 ± 2.0	T: 1.0 ± 2.2 C: 1.2 ± 2.2		T: 75.0 ± 32.6 C: 54.9 ± 30.3	T: 0.2 ± 0.6 C: 0.0 ± 0.8	T: –0.1 ± 0.4 C: –0.3 ± 0.6	Treatment outcomes following surgical therapy of peri-implantitis might be influenced by factors other than the method of surface decontamination.

Schwarz et al. 2013[9]*	RCT	T: MI + GBR + laser C: MI (plastic curet) + GBR	Er:YAG	11.4 J/cm^2, 10 pulses per second	T: 7 C: 10	T: 9 C: 12	48	Peri-implantitis	T: 1.3 ± 1.8 C: 1.2 ± 1.9	T: 1.2 ± 2.0 C: 1.5 ± 2.0		T: 71.6 ± 24.9 C: 85.2 ± 16.4	T: 0.4 ± 0.7 C: 0.0 ± 1.1	T: –0.1 ± 0.3 C: –0.3 ± 0.9	Treatment outcomes following surgical therapy were not influenced by factors other than the method of surface decontamination.

Table 2.

Features of the Included Articles Using a Surgical Approach (continued)

Author/ Year	**Study Design**	**Groups**	**Type**	**Laser Settings**	**Patients (n)**	**Implants (n)**	**Follow-up (months)**	**Diagnosis Mucositis/ Peri-Implantitis**	**Treatment Outcomes (difference; mean ± SD) PD (mm)**	**CAL (mm)**	**MBL (mm)**	**BOP (%)**	**PI**	**REC (mm)**	**Conclusions**
Schwarz et al. 2014[44]	CS	Laser + MI (plastic curets) + implantoplasty + GBR + CTG	Er:YAG	11.4 J/cm^2	10	13	6	Peri-implantitis	2.53 ± 1.80	2.07 ± 1.93		74.4 ± 28.5	0.23 ± 0.59	0.46 ± 0.77	Regenerative and resective surgical therapy with soft tissue grafts might control peri-implantitis lesions without compromising the esthetic outcome.
Bombeccari et al. 2013[39]*	RCT	T: MI + laser C: MI (plastic scaler) + CHX	Diode	810 nm, 1W, 20 seconds × 5	T: 20 C: 20	T: 20 C: 20	6	Peri-implantitis	T: 1.0 ± 0.31 C: 0.30 ± 0.52	T: 0.54 ± 0.09 C: 0.10 ± 0.01		T: 60 ± 50 C: 30 ± 48			A significantly lower proinflammatory index of peri-implantitis was observed in the laser group at 6 months of follow-up.

Papadopoulos et al. 2015[46]	RCT	T: MI + laser C: MI (plastic curets)	Diode	980nm, 0.8W, 3 times	T: 8 C: 8	T: 8 C: 8	6	Peri-implantitis	T: 1.48 C: 1.21	T: 0.65 C: 0.17	T: 57.4 C: 62.5	T: 9.6 C: 16.7	The adjunctive use of the diode laser was not beneficial in the surgical management of peri-implantitis.

GBR = guided bone regeneration; T = test; C = control; MI = mechanical instrumentation; CO_2 = carbon dioxide; Er:YAG = erbium:yttrium-aluminum-garnet; CTG = connective tissue graft; CHX = chlorhexidine.

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