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Comparison of Photodynamic Therapy and Air Abrasion for Implant Surface Decontamination with Laser Treatment in Terms of Efficacy and Implant Surface Alterations: A Systematic Review

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A B S T R A C T

Objectives: Considering the shortcomings of the currently applied mechanical and chemical methods for implant surface decontamination, this study compared the efficacy of three decontamination methods and their impact on implant surface.

Materials and Methods: This systematic review was conducted based on the PRISMA guidelines, with searches performed in PubMed, Scopus, and Web of Science databases. The inclusion criteria were English-language animal, in vivo, and in vitro studies on the effects of photodynamic therapy (PDT), laser treatment, and air abrasion on implant surface changes or microbial load.

Results: Of 1,076 initially retrieved articles, 30 studies were fully reviewed; out of which, 20 met the inclusion criteria. One study found that erbium-doped yttrium-aluminum-garnet (Er:YAG) laser and air abrasion were equally effective in reducing the microbial load, but seven studies favored laser treatment. Five studies noted minor surface changes with air abrasion, while three reported more changes with laser. Regarding biocompatibility, eight studies favored laser; while, three found both methods effective. In six studies, Er:YAG laser was more effective than PDT in reducing the microbial load, with five studies also showing better preservation of implant integrity. Both methods were biocompatible, but laser treatment was superior in preserving cell viability, with three studies favoring it over PDT. Additionally, PDT outperformed air abrasion in reducing the microbial load, preserving the implant surface, and enhancing biocompatibility.

Conclusion: Both PDT and laser therapy are effective in reducing the microbial load. Additionally, laser causes the least surface alterations, with some studies reporting minor improvements in implant surface properties.

Keywords: Air Abrasion, Dental; Decontamination; Dental Implants; Laser Therapy; Photochemotherapy

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INTRODUCTION

Dental implants have become a standard treatment option for patients with partial or complete edentulism. Long-term success rates for dental implants have been reported to exceed 95%, and thus, they are increasingly used for oral rehabilitation in edentulous individuals [1]. Despite the high survival rate, biological complications have also been reported with a considerable, yet variable, frequency (1%-45%). The risk of biological and technical complications remains a major concern for both clinicians and patients [2]. Mucositis, peri-implantitis, and peri-implant diseases are common complications in implant dentistry, with a rising incidence as more patients receive dental implants [3]. Mucositis, peri-implantitis, and peri-implant diseases are caused by localized inflammation around dental implants due to microbial biofilm. Peri-implant mucositis is defined as inflammation confined to the peri-implant soft tissue; while, peri-implantitis also leads to progressive bone loss, compromising implant support and osseointegration [4].

The mean prevalence of peri-implant mucositis is reported to be 48.29% at the implant level and 83.46% at the patient level; while the mean prevalence of peri-implantitis is 25.9% at the implant level, and 19.83% at the patient level [5].

Treatments for mucositis and peri-implantitis include non-surgical and surgical methods, focusing on controlling and eliminating infection through mechanical or chemical debridement. Success depends on creating conditions for tissue regeneration, but implant surface contamination by bacteria and toxins hinders re-osseointegration [6]. Studies have shown that conventional mechanical methods, including the use of manual instruments (such as curettes) and ultrasonic devices, are inadequate for completely removing the bacterial biofilms due to the implant's screw-like design and surface roughness. Therefore, alternative treatment methods have been introduced for implant surface detoxification, including the use of disinfectants or antibiotics, laser therapy, air abrasion, and photodynamic therapy (PDT) [7].

The use of various types of lasers for treatment of periodontal and peri-implant diseases has been evaluated in numerous studies as well [8-14]. Various types of lasers are used for disinfection, including erbium, chromium: yttrium, scandium, gallium, garnet, neodymium-doped yttrium aluminum garnet, erbium: yttrium aluminum garnet (Er:YAG), gallium aluminum arsenide, carbon dioxide, and diode lasers [15]. Er:YAG lasers are effective in disinfecting the implant surfaces and removing bacterial deposits, promoting bone regeneration. However, improper control of laser parameters can cause tissue damage, including bone resorption and implant surface changes [8,16].

Antimicrobial PDT (aPDT), by using a low-level laser and a photosensitizer, is effective in disinfecting implant surfaces and reducing bacterial counts. When combined with guided bone regeneration, it also aids in bone regeneration [8]. However, its efficacy remains limited, and a new combined approach involving aPDT and other disinfecting methods is anticipated in the future [17].

Air abrasion, with various abrasive powders, has been introduced for implant surface disinfection, and causes less surface damage compared to ultrasonic devices or manual instruments. However, careful design and use are imperative to prevent tissue damage, and the retained abrasive particles may affect cell viability by altering the chemical properties of the titanium surface [18].

Mechanical and chemical methods for implant surface decontamination have some challenges, including incomplete biofilm removal, surface damage, and chemical residue deposition. These issues can harm the surrounding tissues, reduce the integrity of the titanium oxide layer, and lower surface biocompatibility. Since implant surface quality (chemical, mechanical, and topographical) is crucial for cellular behavior and re-osseointegration, debridement and decontamination in peri-implantitis treatment should prioritize preserving the surface quality [6].

A study aimed at removing bacterial biofilm using Er:YAG laser compared to other decontamination methods such as PDT,

titanium curettes, and curettes combined with adjunctive PDT, suggested subgingival biofilm removal and decontamination of titanium implant surfaces with Er:YAG laser as a promising approach in need of further investigation [19]. Another systematic review examined the effects of air abrasive methods on titanium surfaces, focusing on surface alterations, decontamination efficacy, and biocompatibility. It compared air abrasion with other disinfection methods such as plastic curettes and Er:YAG laser. The study found that air abrasion effectively removed contaminants without significantly damaging the surface. However, its main limitation was the inability to fully restore the surface's biocompatibility [20]. Additionally, a previous study compared air abrasion with sodium bicarbonate and aPDT for dental implant surface disinfection in vitro. Both protocols showed good decontamination efficacy. However, the ideal clinical protocol remains under investigation due to limitations in the study design [21].

Considering the absence of a systematic review comparing the most effective and efficient methods for implant surface decontamination with minimal adverse effects on implant surfaces, the objective of this systematic review was to evaluate and compare various decontamination methods, including PDT, air abrasion, and laser treatment, in terms of efficacy and implant surface alterations.

MATERIALS AND METHODS

Study design:

This systematic review was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) [22]. Ethical approval was obtained from the Ethics Committee of Tehran University of Medical Sciences (Ethics code: IR.TUMS.DENTISTRY.REC.1402.084).

Eligibility criteria:

This systematic review was carried out according to the PRISMA guidelines. The objective of the study was to compare two methods—PDT and air abrasion—with laser treatment for implant surface decontamination in terms of effectiveness and implant surface changes, following the PICO framework [23].

The PICO components for the study were as follows:

Laser vs. PDT:

***P (Participants)*:** Implants or zirconia/titanium discs, either as alloys or pure forms.

***I (Intervention)*:** Implant surface decontamination using PDT.

***C (Comparison)*:** Comparison of this method with laser treatment.

***O (Outcomes)*:** Primary outcomes: reduction in microbial load and implant surface changes; secondary outcome: biocompatibility.

Laser vs. air abrasion:

***P (Participants)*:** Implants or zirconia/titanium discs, either as alloys or pure forms.

***I (Intervention)*:** Implant surface decontamination using air abrasion devices.

***C (Comparison)*:** Comparison of this method with laser treatment.

***O (Outcomes)*:** Primary outcomes: reduction in microbial load and implant surface changes; secondary outcome: biocompatibility.

PDT vs. air abrasion:

***P (Participants)*:** Implants or zirconia/titanium discs, either as alloys or pure forms.

***I (Intervention)*:** Implant surface decontamination using air abrasion devices.

***C (Comparison)*:** Comparison of this method with PDT.

***O (Outcomes)*:** Primary outcomes: reduction in microbial load and implant surface changes; secondary outcome: biocompatibility

The inclusion criteria were animal studies, and in vivo and in vitro studies examining the effects of various decontamination methods on the implant surface and/or microbial load. The exclusion criterion was studies that did not assess at least two methods under investigation.

Information sources:

A searches was conducted in databases including PubMed, Scopus, and Web of Science for related published articles, in addition to hand searching for the gray literature, without time or language restrictions.

Search strategy:

The search was conducted using combinations of keywords obtained from MeSH and text words according to the guidelines for each database (Table 1).

Table 1. Search strategy in each database

PubMed	Scopus	Web of Science
#1Dental Implants[Mesh] OR dental implants*[Title/Abstract] #2 air abrasion[mesh] OR air abrasive*[Title/Abstract] OR air polishing*[Title/Abstract] OR prophy jet*[Title/Abstract] OR Lasers[Mesh] OR laser*[Title/Abstract] OR photochemotherapy[mesh] OR photodynamic therapy *[Title/Abstract] OR PDT *[Title/Abstract] OR aPDT *[Title/Abstract] OR Er:YAG laser[mesh] OR erbiumdoped yttrium aluminum garnet laser*[Title/Abstract] #3 cleaning efficacy*[Title/Abstract] OR cleaning efficiency*[Title/Abstract] OR biofilm removal*[Title/Abstract] OR bacterial load[Mesh] OR bacterial count[Mesh] OR surface alterations*[Title/Abstract] OR surface changes*[Title/Abstract] OR surface modification*[Title/Abstract] OR surface damage*[Title/Abstract] OR Decontamination[Mesh] OR disinfection[mesh] OR detoxification[mesh] OR Sterilization [Mesh] OR surface decontamination *[Title/Abstract] #1 AND #2AND #3AND	#1 (TITLE-ABS-KEY ((“dental implants” OR “dental implants”))) #2 (TITLE-ABS-KEY ((“air abrasion” OR “air abrasive” OR “air polishing” OR “prophy jet” OR “Lasers” OR “laser” OR “Er:YAG laser” OR “erbiumdoped yttrium aluminum garnet laser” OR “photochemotherapy” OR “ PDT”))) #3 (TITLE-ABS-KEY ((“cleaning efficacy” OR “cleaning efficiency” OR “biofilm removal” OR “bacterial load” OR “bacterial count” OR “surface alterations” OR “surface changes” OR “surface modification” OR “Decontamination” OR “disinfection” OR “detoxification” OR “Sterilization”))) #1AND #2 AND #3 AND	#1 “dental implants” OR “dental implants” #2 “air abrasion” OR “air abrasive” OR “air polishing” OR “prophy jet” OR “Lasers” OR “laser” OR “Er:YAG laser” OR “erbiumdoped yttrium aluminum garnet laser” OR “photochemotherapy” OR “ PDT” #3 “cleaning efficacy” OR “cleaning efficiency” OR “biofilm removal” OR “bacterial load” OR “bacterial count” OR “surface alterations” OR “surface changes” OR “surface modification” OR “Decontamination” OR “disinfection” OR “detoxification” OR “Sterilization” #1 AND #2 AND #3 AND

Study selection:

The article selection process was carried out by two independent researchers. After searching the articles, their abstracts were imported into Rayyan software (Rayyan company, Cambridge, USA), where duplicates were removed. Initial screening was performed based on the title and abstract of the studies. If the study was relevant and suitable, its full text was retrieved and carefully evaluated according to the eligibility criteria. Any disagreement between the two researchers was resolved through discussion.

Data collection and extraction:

Based on the study objectives, relevant data were extracted from the included studies, and tabulated. The extracted information included study title, author information, year of publication, country of study, type of study, type of implants evaluated, number of implants, implant surface design, treatment methods used, number of control and experimental groups, types of microbiota present, microbial load (if applicable), laboratory tests performed, and study results—such as the impact on microbial load, qualitative and quantitative changes in the implant surface, and biocompatibility levels.

Risk of bias assessment:

Two researchers independently assessed the risk of bias and quality of in vivo studies using the Cochrane risk of bias tool [24] and the CONSORT statement [25]. Disagreements were resolved through discussion with a third researcher. Graphs and charts were generated using RevMan 5.4 software version 5.4 (The Cochrane Collaboration, 2020) [26]. Accordingly, the studies were categorized into three risk levels: low risk, unclear, and high risk of bias, based on the following components:

1. Random sequence generation
2. Allocation concealment
3. Blinding of participants and personnel
4. Blinding of outcome assessors
5. Selective outcome reporting

For in vitro studies, the risk of bias and validity of the results were independently assessed by two researchers using the QUIN tool [27], a standardized tool for in vitro studies. Disagreements were again resolved through discussion with a third researcher. The QUIN tool consists of a scoring sheet with 12 elements to evaluate potential biases. Studies were scored based on the clarity of each component, as follows:

- Clearly defined (score 2)
- Poorly defined (score 1)
- Not defined (score 0)
- For components that were not applicable, "not applicable" was recorded.

The final score for each study was calculated using the following formula:

$$Final\ score = \frac{total\ scores \times 100}{2 \times number\ of\ applicable\ components\ used}$$

The final scores were used to classify in vitro studies as having low, medium, or high risk of bias:

-Low risk: >70%
-Medium risk: 50%-70%
-High risk: <50%

Data synthesis:

Due to the diversity in methodologies and study outcomes, conducting a meta-analysis was not possible. Instead, systematic categorization and qualitative comparison of the studies were performed.

RESULTS

After conducting an electronic search across databases, 1,076 articles were identified, along with 5 additional relevant studies from manual searches. After removing the duplicates, 575 studies remained for the title and abstract screening. Following this initial screening, 551 articles were excluded. The full-text of the remaining 24 articles was then reviewed. If the full-text was not accessible, the authors were contacted. Four additional articles were excluded, either because they did not meet the inclusion criteria or because the authors did not respond. Ultimately, 20 articles were included in the study based on the inclusion and exclusion criteria.

The flowchart of the search results, according to the PRISMA guidelines, is presented in Figure 1.

Characteristics of the sources of evidence:

In vitro studies:

Out of 13 in vitro studies reviewed [19,21,28-38]:

- Seven studies [28-34] focused on comparing laser therapy and air abrasion methods.
- Five studies [19,35-38] evaluated laser therapy and PDT.
- One study [21] compared PDT and air abrasion.

In vivo studies:

Out of 5 in vivo studies included [6,8,39-41]:

- Two studies [40,41] examined and compared laser therapy with air abrasion.
- Three studies [6,8,39] focused on comparing laser therapy with PDT.

Ex vivo studies:

Both of the included ex vivo studies [42,43] focused on comparing laser therapy with air abrasion.

Critical appraisal within sources of evidence:

A summary of the risk of bias assessment for the in vitro and ex vivo studies is presented in Table 2. Based on the QUIN tool, most studies exhibited high risk in the following criteria: sample size determination, blinding, details regarding the operator, and details about the evaluator. However, most studies were rated low risk for the criteria related to the overall aim/specific objectives, sampling method, details of study groups, methodology, statistical analysis, and results.

Ultimately, using this tool, 3 studies [31,35,43] were classified as having low risk of bias, 10 studies [19,21,28-30,32,33,36,38,42] as having moderate risk, and 2 studies [34,37] as having high risk of bias.

The summary of risk of bias assessment for in vivo studies is presented in Figures 2 and 3. Based on the Cochrane tool, most studies were rated as low risk for the following criteria: blinding of participants and personnel, blinding of outcome assessors, and selective reporting of outcomes. However, there was unclear risk in terms of random sequence generation and allocation concealment.

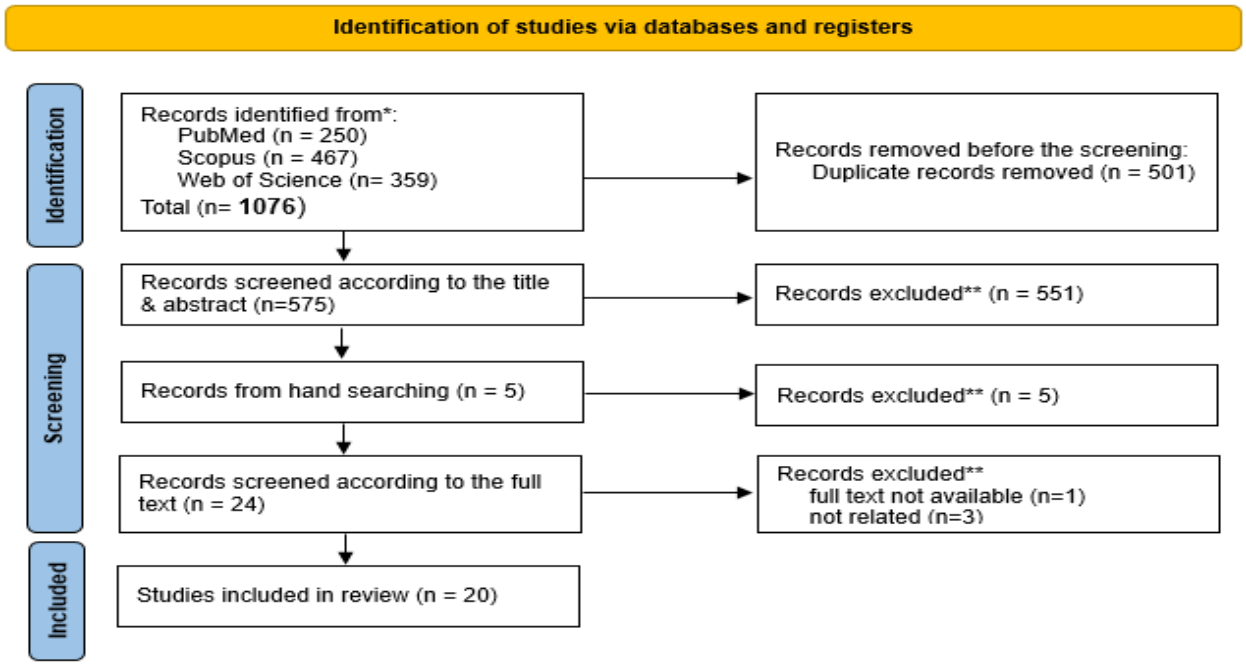

Fig 1. Flow chart of search strategy

Table 2. A summary of risk of bias assessment for in vitro and ex vivo studies

Reference Number	Overall aim/specific objectives	Sample size determination	Sampling method	Study group details	Methodology details	Operator details	Randomization	Outcome measurement methods	Evaluator details	Blinding	Statistical analysis	Results	Final score	Risk of bias status
[28]	2	0	2	2	2	1	N/A	2	0	0	2	2	15	Moderate
[37]	2	0	0	1	1	0	N/A	0	0	0	1	1	6	High
[33]	2	0	2	2	2	0	N/A	2	0	0	1	2	13	Moderate
[31]	2	0	2	2	2	1	N/A	2	1	0	2	2	16	Low
[21]	1	0	2	2	2	1	N/A	2	1	0	1	2	14	Moderate
[43]	2	0	2	2	2	1	2	2	1	2	2	2	20	Low
[36]	1	0	2	1	2	0	N/A	2	0	0	1	2	11	Moderate
[42]	2	0	2	2	2	0	0	2	1	0	2	2	13	Moderate
[19]	2	0	2	2	2	0	N/A	2	0	0	2	2	14	Moderate
[32]	2	0	1	2	2	0	N/A	2	0	1	1	2	12	Moderate
[35]	2	0	2	2	2	1	N/A	2	1	0	2	2	16	Low
[34]	1	0	2	2	2	0	N/A	1	0	0	1	1	10	High
[30]	2	0	2	2	2	0	N/A	2	0	0	1	2	13	Moderate
[38]	1	0	2	2	2	0	N/A	2	0	0	2	1	12	Moderate
[29]	2	0	2	1	2	0	N/A	1	0	0	2	2	12	Moderate

N/A: Not Applicable

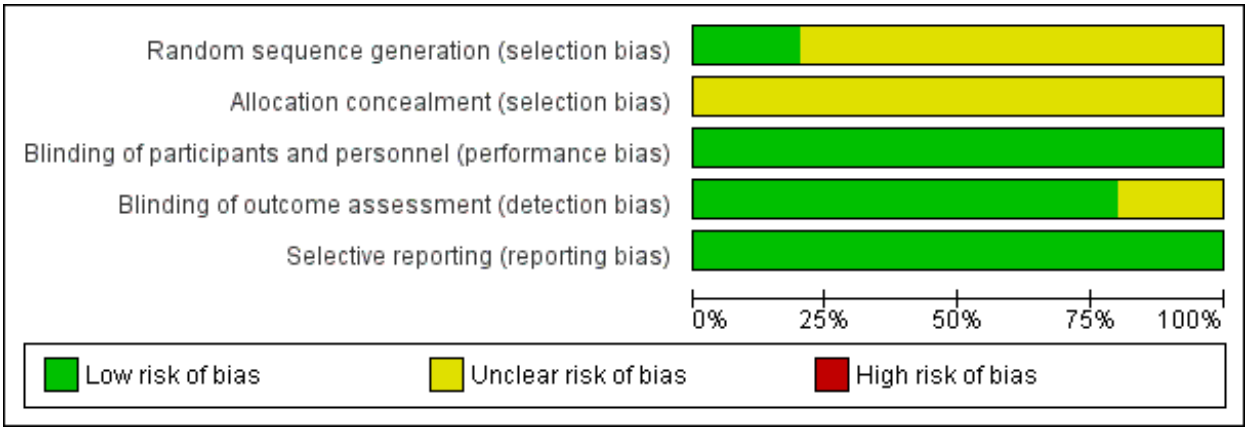

Fig 2. Risk of bias assessment for in vivo studies based on the Cochrane tool

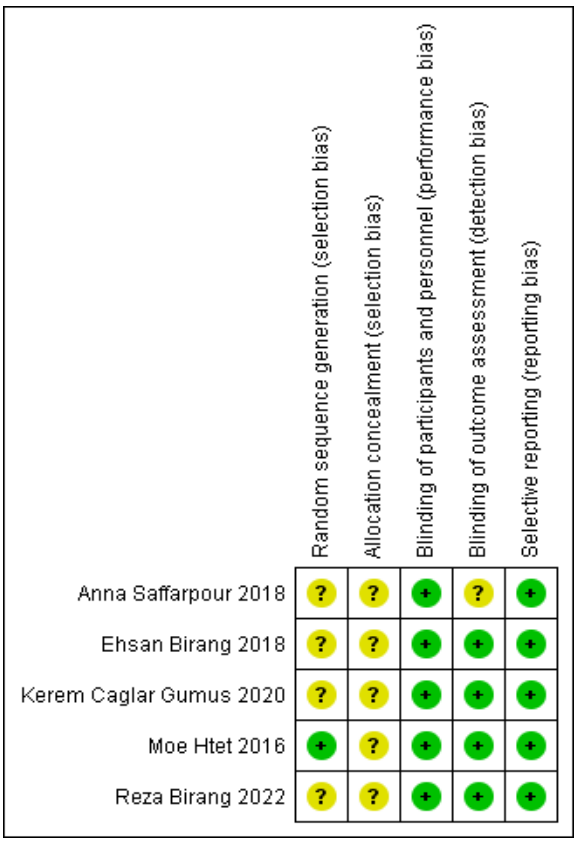

Fig 3. Domain-specific risk of bias assessment for in vivo studies based on the Cochrane tool

Ultimately, according to this tool, 4 studies [8,39,40,41] were classified as having a low risk of bias, and 1 study [6] was classified as having an unclear risk of bias.

Results of individual source evidence:

In vitro studies:

Of 7 in vitro studies comparing laser therapy and air abrasive methods [28-34], one study by Stein et al. [28] reported that both methods were equally effective in reducing the microbial load. However, in 5 other studies [29-33], although both laser and air abrasive methods were recognized as effective, laser therapy showed significantly greater effectiveness in reducing the microbial load. Additionally, Chen et al. [34] indicated that air abrasion was slightly more effective than laser therapy in reducing the microbial load.

Regarding implant surface changes, Stein et al. [28] observed a slight increase in the percentage of Ti after air abrasion with glycine powder. Two other studies [29,32] reported the preservation of surface integrity after laser therapy; while, Amid et al. [31] showed no change in implant surface hardness, an increase in Ti content, and a reduction in carbon content after laser treatment. In another study, Schmage et al. [30] reported a slight increase in implant surface hardness after air abrasion; while, another study [33] did not assess this variable.

In terms of biocompatibility, Amid et al. [31] reported improvements in biocompatibility and increased wettability following both laser therapy and air abrasion, indicated by a reduction in contact angle. Another study also evaluated cell viability and secretion of lactate dehydrogenase to measure cytotoxicity and secretion of caspase 3/7 to assess apoptosis. Both laser therapy and air abrasion showed the highest cell viability and the lowest cytotoxicity and apoptosis [28]. In contrast, 4 other studies [29,30,32,33] reported that laser therapy yielded greater improvements in cell viability and biocompatibility.

Of 5 other in vitro studies comparing laser

therapy and PDT [19,35-38], 3 studies [19,35,36] noted that laser therapy was more effective than PDT in reducing the microbial load. However, Vaddamanu et al. [37] indicated that both laser therapy and PDT had a positive efficacy for reducing the microbial load, and concluded that PDT was slightly more effective than laser therapy. Giannelli et al. [38] compared laser therapy and PDT (using LED and diode laser) with other methods of implant surface decontamination, and found that laser therapy and PDT with LED were superior in reducing the microbial load.

Regarding implant surface changes, 3 studies [19,35,36] confirmed that the surface integrity of the implant was preserved after laser therapy, and surface hardness remained unchanged. One other study [38] showed no change in implant surface after PDT, and one study did not assess this variable [37].

In terms of biocompatibility, Giannelli et al. [38] demonstrated improved biocompatibility by both methods, but due to a slight reduction in cell viability after PDT using diode laser and LED, the results indicated superiority of laser therapy in terms of biocompatibility compared to PDT. Three other studies [19,35,36] also indicated that laser therapy was a better method to improve biocompatibility, while one study did not address this variable [37]. Batalha et al. [21] compared PDT and air abrasion, and showed that both methods resulted in a reduction in microbial load, but PDT demonstrated the lowest colony count. However, it was reported that despite the reduction in bacteria, none of the methods could cause complete eradication of the bacteria.

In vivo studies:

Among 5 in vivo studies [6,8,39-41], 3 [6,8,39] examined and compared laser therapy and PDT. In terms of reducing the microbial load, 2 studies [8,39] indicated that laser therapy was significantly more effective than PDT. Additionally, Saffarpour et al. [6] reported that both methods were effective in reducing the microbial load but concluded that laser therapy had a slightly greater effect.

Regarding surface changes, 2 studies [8,39] indicated preservation of implant surface integrity after laser therapy, while one study [6] showed a slight increase in surface hardness after PDT.

In terms of biocompatibility, 2 studies [8,39] demonstrated improved cell viability with laser therapy. Saffarpour et al. [6] regarded biocompatibility as a comparable variable for both methods, stating that none of the methods compromised implant biocompatibility.

Two other in vivo studies [40,41] compared laser therapy and air abrasion. Birang et al. [40] reported that laser therapy had the highest efficacy for reducing the microbial load compared to air abrasion, and an increase in viability of human dental pulp stem cells was observed in the laser group. They did not mention anything about the implant surface changes in their study. In a study by Gümüş et al, [41] both laser therapy and air abrasion with nano-hydroxyapatite particles effectively reduced the microbial load on implant surfaces while preserving the morphology and enhancing the wettability of implant surface. These treatments improved biocompatibility and surface properties with comparable effectiveness.

Ex vivo studies:

Out of 20 studies finally included in this study [6,8,19,21,28-43], 2 [42,43] were ex vivo studies comparing laser therapy and air abrasion. El Chaar et al. [42] showed that although both methods were effective in reducing the microbial load, laser therapy caused a slightly greater reduction. Additionally, they reported an increase in Ti levels on the implant surface after laser therapy, with improved cell viability.

In contrast, Otsuki et al. [43] showed that both laser and air abrasion reduced bacterial load, but air abrasion was found to be more effective. It also increased implant surface hardness. Their results highlighted the potential of air abrasion for cleaning without compromising biocompatibility. Their study also raised concerns about the safety of laser treatments for the surrounding tissues if settings are not carefully adjusted. Details and summaries of the reviewed articles are presented in Table 3. The important parameters for using each decontamination method are also presented in Table 4.

Table 3. Details and summaries of the reviewed articles

Ref. Number/ study type	Type of implant	Type of treatment	Microbiota	Key results	Surface changes	Biocompatibility
[28]/ in vitro	Zirconia/ Titanium	Air abrasion (G/E)/ laser	*Aggregatibacter actinomycetemcomitans*, *Actinomyces viscosus*, *Streptococcus sanguinis*	Air abrasion (GPAP, EPAP) and Er:YAG laser were effective in reducing microbial load	Increased Ti percentage post-GPAP. Reduced surface roughness for zirconium discs.	Laser therapy and air abrasion: the highest rate of cell viability, and the lowest rate of cytotoxicity and apoptosis (increased LDH secretion indicating better cell viability in both groups). ✓LDH secretion (measure for cytotoxicity), cell viability, and caspase 3/7 activity (measure for apoptosis); air-polishing abrasives and laser irradiation showed the highest cell viability along with low cytotoxicity and apoptosis. There was a reduced number of viable cells on zirconium samples after laser irradiation after 24 h of culture).
[37]/ in vitro	Titanium	Laser/PDT	*Streptococcus gordonii*, *Actinomyces naeslundii*	Both treatments significantly reduced bacterial counts, with PDT being more effective	Not specified	Not specified
[40]/in vivo	Titanium	Air abrasion (G)/laser	Aerobic and anaerobic bacterial colonies	Er:YAG laser showed the highest efficacy in microbial load reduction compared to air abrasion	Not specified	Higher viability of hDPSCs with Er:YAG laser treatment
[33]/in vitro	Titanium	Air abrasion (G)/ laser	*Escherichia coli*	hDPSCs showed higher viability and proliferation on SLA-treated implants with laser treatment	Not specified	Er:YAG laser treatment improved cell viability

Table 3 cont'd

[21]/in vitro	Titanium	Laser/ air abrasion (G)	*Escherichia coli*	Laser treatment did not significantly alter surface roughness but improved Ti percentage	Carbon reduction noted post-laser treatment	Improving biocompatibility by reducing contact angle and increasing wettability in laser group
[31]/in vitro	Titanium	Air abrasion (sodium bicarbonate)/ PDT	*Porphyromonas gingivalis*	PDT caused significant bacterial reduction compared to air abrasion. The aPDT group, even showing greater efficacy, was not able to completely eliminate the microbial biofilm from the implant surface	Not specified	Not specified
[43]/ex vivo	Titanium	Laser/air abrasive	*Staphylococcus aureus*, *Escherichia coli*	Both methods effectively reduced bacterial loads, with air abrasion showing slightly better performance.	Slight increase in surface roughness post-air abrasion	Comparable cell viability in both treatments. Air abrasion with glycine powder was discussed regarding its potential to clean implant surfaces without compromising biocompatibility. Lasers' biocompatibility and safety for peri-implant tissue may be compromised without careful control of its settings.
[42]/in vitro	-	Laser/PDT	*Candida albicans*	Laser treatment was more effective in reducing fungal load compared to PDT.	Surface roughness unchanged post-laser treatment	Laser treatment improved biocompatibility
[36]/ex vivo	Titanium	Laser/ air abrasion (sodium bicarbonate)	*Streptococcus mutans*	Air abrasion and laser treatment both significantly reduced microbial load, with laser being slightly more effective.	Increased Ti percentage post-laser treatment	Enhanced cell viability with laser treatment

Table 3 cont'd

[41]/in vivo	Titanium	Laser/ air abrasion (nano-HA)	*Actinomyces israelii*	Both treatments showed significant bacterial reduction.	The nano-HA methods preserved the surface morphology better than mechanical and laser methods.	Comparable biocompatibility in both treatments. When the groups were examined for wettability, the lowest CA degrees were observed in the short-term airflow, long-term airflow, and laser groups
[39]/in vivo	Titanium	Laser/ PDT	*Fusobacterium nucleatum*	Laser treatment showed higher efficacy in bacterial reduction compared to PDT	Surface integrity maintained post-laser treatment	Improved cell viability with laser treatment
[6]/in vivo	Titanium	Laser/ PDT	*Aggregatibacter actinomycetemcomitans*	PDT and laser treatments were both effective in microbial reduction, with laser being slightly better.	Minor increase in surface roughness post-PDT treatment.	Comparable biocompatibility in both treatments. The tested decontamination methods did not compromise the surface's biocompatibility.
[19]/in vitro	Titanium	Laser/PDT	*Streptococcus gordonii*, *Actinomyces naeslundii*, *Fusobacterium nucleatum*, *Campylobacter rectus*, *Filifactor alocis*, *Eikenella corrodens*, *Prevotella intermedia*, *Parvimonas micra*, *Porphyromonas gingivalis*, *Tannerella forsythia*, *Treponema denticola* and *Aggregatibacter actinomycetemcomitans*	Er:YAG laser was more effective in microbial load reduction compared to PDT.	Surface roughness maintained post-laser treatment	Enhanced cell viability with Er:YAG laser treatment

Table 3 cont'd

[32]/in vitro	Ti	Laser/air abrasion (G)	*Escherichia coli*	Both methods significantly reduced bacterial counts, with laser treatment being slightly more effective	Minimal changes in surface properties post-laser treatment	Improved biocompatibility with laser treatment
[35]/ in vitro	Ti	Laser/PDT	*Streptococcus mutans*, *Aggregatibacter actinomycetemcomitans*	Er:YAG laser was more effective in bacterial reduction compared to PDT.	Surface properties preserved post-laser treatment.	Enhanced biocompatibility with Er:YAG laser treatment.
[34]/in vitro	Ti	Laser/Air abrasion (G)	*Escherichia coli*	Air abrasion and laser were both effective in bacterial reduction, with air abrasion being more effective.	Increased surface roughness post-air abrasion treatment.	Comparable cell viability in both treatments.
[8]/in vivo	Ti	Laser/PDT	*Streptococcus sanguinis*	Laser treatment showed higher efficacy in microbial reduction compared to PDT	Surface integrity preserved post-laser treatment	Improved biocompatibility with laser treatment
[30]/in vitro	Ti	Laser/air abrasion (G)	*Streptococcus mutans*	Both methods significantly reduced microbial loads, with laser treatment being slightly more effective.	Minor increase in surface roughness post-air abrasive treatment.	Enhanced cell viability with laser treatment
[38]/in vitro	Ti	Laser/PDT	*Porphyromonas gingivalis*	Both treatments showed significant bacterial reduction, with laser being more effective.	Surface roughness maintained post-PDT treatment.	Comparable biocompatibility in both treatments, but enhanced cell viability with Er:YAG laser treatment.
[29]/in vitro	Ti	Laser/air abrasion	*Porphyromonas gingivalis*	Laser treatment was more effective in reducing microbial load compared to air abrasion.	Surface integrity preserved post-laser treatment.	Enhanced biocompatibility with laser treatment.

Ref: reference; G: glycine; E: erythritol; GAPA: glycine powder air polishing; EPAP: erythritol powder air polishing; PDT: photodynamic therapy; Er:YAG laser: erbium-doped yttrium aluminum garnet laser; hDPSCs: human dental pulp stem cell; SLA*:* sandblasted, large-grit acid-etched; LDH: lactate dehydrogenase; *n*-HA: nano-hydroxyapatite; Ti: Titanium

Table 4. Important parameters in implant surface decontamination tools

Ref.	Air abrasion	Laser			PDT	
	Powder type	wave length (nm)	Type of laser	Frequency (Hz)	Type of photosensitizer	Type of laser (wavelength)
[28]	Erythritol/glycine	X	Er:YAG	50	-	-
[37]	-	X	Er:YAG	20	X	X
[40]	Glycine	2940	Er:YAG	10	-	-
[33]	Glycine	2940	Er:YAG	10	-	-
[21]	extra-fine granulation Sodium bicarbonate	2940	Er:YAG	10	-	-
[31]	Glycin	-	-	-	Toluidine blue O	Red laser: Whitening Lase II (660nm)
[43]	"AIR-FLOW® PERIO POWDER (Glycin based)	X	Er:YAG	-	-	-
[42]	Sodium bicarbonate	X	Er:YAG	20	3,7-bis (dimethyl-amino) phenazathionium chloride trihydrate (methylene blue)	Diode (660-675nm)
[36]	-	X	Er:YAG	30	-	-
[41]	Nano-hydroxyapatite	X	Er:YAG	10	-	-
[39]	-	2940	Er:YAG	10	tolonium chloride	Diode (660nm)
[6]	-	2,940	Er:YAG	10	G1=toluidine blue O G2=ICG-based	G1=LED (635–635nm) G2=Diode (810nm)
[19]	-	X	Er:YAG	-	phenothiazine chloride	Diode (660nm)
[32]	Glycine-based perio powder	L1, L2, L3= 2940	Er:YAG	L1, L2, L3= 10	-	-
[35]	-	X	Er:YAG	10	PDT1=TBO PDT2=ICG-based	PDT1=LED (630nm) PDT2=Diode (810nm)
[34]	Glycine	2940	Er:YAG	10	-	-
[8]	-	2940	Er:YAG	10	toluidine blue O	Diode (830nm)
[30]	low abrasive amino acid–Glycine powder	2940	Er:YAG	-	-	-
[38]	-	2940	Er:YAG	10	methylene blue	PDT1=Diode (630nm) PDT2=LED (630nm)
[29]	-	2940	Er:YAG	-	-	-

Ref.: reference number; X: not mentioned

DISCUSSION

Peri-implantitis is an inflammatory condition caused by bacterial infection and biofilm buildup on dental implants, leading to bone loss and potential implant failure. Effective mechanical or chemical decontamination is crucial for treatment of peri-implantitis, restoring osseointegration, and ensuring long-term implant success [44].

After analyzing the studies, the results consistently demonstrated that both PDT and air abrasion were effective in reducing the microbial load on implant surfaces [21,28,34,37,43]. However, laser treatments, especially Er:YAG were highly effective in reducing the microbial load by precisely targeting and dissolving bacterial biofilms. Multiple studies confirmed the superior efficacy of laser therapy for elimination of pathogenic microorganisms [6,8,19,30,32,35,36,39,40,42]. PDT also showed high efficacy in reducing the bacterial count but was generally found to be less effective compared to laser treatment [6,8,19,35,36,38,39]. The effectiveness of PDT depends on factors like the photosensitizer type, light exposure time, and targeted microbial species, yet it remains valuable for its non-invasive approach and broad-spectrum antimicrobial action [37].

A key factor in implant surface disinfection is preserving or enhancing the surface properties. Laser treatments have been shown to maintain or improve implant integrity, increasing titanium content and reducing contaminants like carbon, which improve implant longevity and performance [31,42].

Air abrasion methods can increase implant surface roughness, which may improve osseointegration by providing a larger surface area for attachment. However, excessive roughness can increase the risk of plaque accumulation, potentially leading to peri-implantitis [30,34,43].

Biocompatibility is crucial for dental implant success, and studies show that laser treatments, especially Er:YAG laser, significantly improve it. Laser-treated surfaces enhance cell survival and promote the proliferation of human dental pulp stem cells, creating a more favorable environment for osseointegration [33,36,40]. PDT also showed improvements in biocompatibility, primarily through significant reductions in bacterial load, thereby minimizing the risk of infection and inflammation around the implant site. However, the degree of biocompatibility improvement with PDT was generally less compared to laser treatment [6,8,19,35,36,38,39].

This systematic review highlights the key clinical implications for choosing disinfection methods in dental implantology. Laser treatments, particularly Er:YAG lasers, stand out for their superior effectiveness in reducing microbial load while preserving or enhancing implant surface properties, making them a preferred option. PDT offers a non-invasive, broad-spectrum alternative antimicrobial modality, especially useful for patients with contraindications for laser treatments or as a complementary method. Air abrasion methods, while effective in reducing the microbial load, require caution due to their potential impact on implant surface roughness, which could affect bone integration. Dentists must carefully weigh these factors to optimize treatment outcomes.

Other reviews have also reported varying results in this area. Mellado-Valero et al. [45] reviewed various methods for disinfecting dental implant surfaces in peri-implantitis treatment, including mechanical and chemical methods, laser therapy, and PDT. Mechanical methods alone are insufficient but have an improved performance when combined with chemical agents like chlorhexidine. Laser treatments, particularly with Er:YAG laser, show promise in biofilm removal without damaging implants, and PDT offers an alternative approach. This review concluded that no single method is definitively superior, and long-term clinical studies are necessary to establish reliable treatment protocols. Another review by Dhaliwal et al. [46] evaluated 17 disinfection methods for microbial biofilms on dental implants as the primary cause of peri-implantitis. Methods included mechanical cleaning, lasers, PDT, air abrasion, and chemical treatments. The study

concluded that while these techniques were generally effective in biofilm prevention and removal, no single method consistently outperformed others. Further research is needed to optimize these approaches for improved clinical outcomes. Additionally, a systematic review by Ramanauskaite et al [47] analyzed six randomized clinical trials to compare decontamination methods like air abrasion, titanium brushes, and Er:YAG lasers with standard peri-implantitis treatments. While titanium brushes showed potential in reducing inflammation, the overall evidence remained inconclusive. Their review highlighted the need for further research to establish a clear standard of care for peri-implantitis treatment.

The present results emphasize the need for further research to optimize parameters for PDT and laser treatments to enhance efficacy and safety. Standardized protocols, including specific photosensitizers, laser wavelengths, and energy settings, are recommended, along with long-term clinical trials to assess the disinfection durability and implant success rates. Additionally, comprehensive studies are needed to address diverse microbial species and a wider range of clinical scenarios.

CONCLUSION

The current data indicated that PDT and air abrasion are effective for disinfection of implant surfaces. However, laser treatments, particularly with Er:YAG laser, result in greater microbial reduction and enhanced biocompatibility. Additionally, laser treatments generally result in minimal changes in implant surface quality, with some studies reporting slight improvements in surface properties. These findings support a clinical preference for laser treatments in implant surface disinfection while recognizing the valuable role of PDT. However, careful attention to the impact on surface properties is essential when selecting the appropriate disinfection method to ensure the long-term success of dental implants.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Pjetursson BE, Heimisdottir K. Dental implants - are they better than natural teeth? Eur J Oral Sci. 2018 Oct;126 Suppl 1:81-7.
2. Cosgarea R, Sculean A, Shibli JA, Salvi GE. Prevalence of peri-implant diseases - a critical review on the current evidence. Braz Oral Res. 2019 sep;33(Suppl 1):e063.
3. Romanos GE, Javed F, Delgado-Ruiz RA, Calvo-Guirado JL. Peri-implant diseases: a review of treatment interventions. Dent Clin North Am. 2015 Jan;59(1):157-78.
4. Figuero E, Graziani F, Sanz I, Herrera D, Sanz M. Management of peri-implant mucositis and peri-implantitis. Periodontol 2000. 2014 Oct;66(1):255-73.
5. Rokaya D, Srimaneepong V, Wisitrasameewon W, Humagain M, Thunyakitpisal P. Peri-implantitis update: Risk indicators, diagnosis, and treatment. Eur J Dent. 2020 Oct;14(4):672-82.
6. Saffarpour A, Nozari A, Fekrazad R, Saffarpour A, Heibati MN, Iranparvar K. Microstructural evaluation of contaminated implant surface treated by laser, photodynamic therapy, and chlorhexidine 2 percent. Int J Oral Maxillofac Implants. 2018 Sep/Oct;33(5):1019-26.
7. Ntrouka VI, Slot DE, Louropoulou A, Van der Weijden F. The effect of chemotherapeutic agents on contaminated titanium surfaces: a systematic review. Clin Oral Implants Res. 2011 Jul;22(7):681-90.
8. Htet M, Madi M, Zakaria O, Miyahara T, Xin W, Lin Z, et al. Decontamination of anodized implant surface with different modalities for peri-implantitis treatment: Lasers and mechanical debridement with citric acid. J Periodontol. 2016 Aug;87(8):953-61.
9. Romanos GE. Lasers and Implants. In: Romanos GE, editor. Advanced Laser Surgery in Dentistry. Springer; Switzerland; 2021 Jan. 185-207.
10. Kubasiewicz-Ross P, Fleischer M, Pitułaj A, Hadzik J, Nawrot-Hadzik I, Bortkiewicz O, et al. Evaluation of the three methods of bacterial decontamination on implants with three different surfaces. Adv Clin Exp Med. 2020 Feb;29(2):177-82.
11. Kwaśniak P, Pura J, Zwolińska M, Wieciński P, Skarżyński H, Olszewski L, et al. Laser and chemical surface modifications of titanium grade 2 for medical application. Appl Surf Sci. 2015 May;336:267–73.
12. Deppe H. CO2 laser therapy of peri-implant infections - Basics and therapeutic recommendations. Aesthet Zahnmed. 2005 Jan;8(1):50-4.
13. Kuo HN, Mei HI, Liu TK, Liu TY, Lo LJ, Lin CL. In vitro laser treatment platform construction with dental implant thread surface on bacterial adhesion for peri-Implantitis. Biomed Res Int. 2017;2017:4732302.

14. Huang P, Chen X, Chen Z, Chen M, He J, Peng L. Efficacy of Er:YAG laser irradiation for decontamination and its effect on biocompatibility of different titanium surfaces. BMC Oral Health. 2021 Dec ;21(1):649.
15. Pranno N, Cristalli MP, Mengoni F, Sauzullo I, Annibali S, Polimeni A, et al. Comparison of the effects of air-powder abrasion, chemical decontamination, or their combination in open-flap surface decontamination of implants failed for peri-implantitis: an ex vivo study. Clin Oral Investig. 2021 May;25(5):2667-76.
16. Louropoulou A, Slot DE, Van der Weijden F. Influence of mechanical instruments on the biocompatibility of titanium dental implants surfaces: a systematic review. Clin Oral Implants Res. 2015 Jul;26(7):841-50.
17. Ohba S, Sato M, Noda S, Yamamoto H, Egahira K, Asahina I. Assessment of safety and efficacy of antimicrobial photodynamic therapy for peri-implant disease. Photodiagnosis Photodyn Ther. 2020 Sep;31:101936.
18. Schwarz F, Ferrari D, Popovski K, Hartig B, Becker J. Influence of different air-abrasive powders on cell viability at biologically contaminated titanium dental implants surfaces. J Biomed Mater Res B Appl Biomater. 2009 Jan;88(1):83-91.
19. Eick S, Meier I, Spoerlé F, Bender P, Aoki A, Izumi Y, et al. In vitro activity of Er:YAG laser in comparison with other treatment modalities on biofilm ablation from implant and tooth surfaces. PLoS One. 2017 Jan;12(1):e0171086.
20. Moharrami M, Perrotti V, Iaculli F, Love RM, Quaranta A. Effects of air abrasive decontamination on titanium surfaces: A systematic review of in vitro studies. Clin Implant Dent Relat Res. 2019 Apr;21(2):398-421.
21. Batalha VC, Bueno RA, Fronchetti Junior E, Mariano JR, Santin GC, Freitas KMS, et al. Dental implants surface in vitro decontamination protocols. Eur J Dent. 2021 Jul;15(3):407-11.
22. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med. 2018 Oct;169(7):467-73.
23. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg. 2010;8(5):336-41.
24. Higgins JP, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011 Oct;343:d5928.
25. Falci SG, Marques LS. CONSORT: when and how to use it. Dental Press J Orthod. 2015 May-Jun;20(3):13-5.
26. Schmidt L, Shokraneh F, Steinhausen K, Adams CE. Introducing RAPTOR: RevMan parsing tool for reviewers. Syst Rev. 2019 Jun;8(1):151.
27. Sheth VH, Shah NP, Jain R, Bhanushali N, Bhatnagar V. Development and validation of a risk-of-bias tool for assessing in vitro studies conducted in dentistry: The QUIN. J Prosthet Dent. 2024 Jun;131(6):1038-42.
28. Stein JM, Conrads G, Abdelbary MMH, Yekta-Michael SS, Buttler P, Glock J, et al. Antimicrobial efficiency and cytocompatibility of different decontamination methods on titanium and zirconium surfaces. Clin Oral Implants Res. 2023 Jan;34(1):20-32.
29. Kreisler M, Kohnen W, Christoffers AB, Götz H, Jansen B, Duschner H, et al. In vitro evaluation of the biocompatibility of contaminated implant surfaces treated with an Er : YAG laser and an air powder system. Clin Oral Implants Res. 2005 Feb;16(1):36-43.
30. Schmage P, Thielemann J, Nergiz I, Scorziello TM, Pfeiffer P. Effects of 10 cleaning instruments on four different implant surfaces. Int J Oral Maxillofac Implants. 2012 Mar-Apr;27(2):308-17.
31. Amid R, Kadkhodazadeh M, Mojahedi SM, Gilvari Sarshari M, Zamani Z. Physicochemical changes of contaminated titanium discs treated with erbium-doped yttrium aluminum garnet (Er:YAG) laser irradiation or air-flow abrasion: An in vitro study. J Lasers Med Sci. 2021 Nov;12:e67.
32. Hakki SS, Tatar G, Dundar N, Demiralp B. The effect of different cleaning methods on the surface and temperature of failed titanium implants: an in vitro study. Lasers Med Sci. 2017 Apr;32(3):563-71.
33. Kadkhodazadeh M, Amid R, Gilvari Sarshari M, Mojahedi M, Parhizkar A. A comparison of human dental pulp stem cell activity cultured on sandblasted titanium discs decontaminated with Er:YAG laser and air-powder abrasion: an in vitro study. Lasers Med Sci. 2022 Oct;37(8):3259-68.
34. Chen CJ, Ding SJ, Chen CC. Effects of surface conditions of titanium dental implants on bacterial adhesion. Photomed Laser Surg. 2016 Sep;34(9):379-88.
35. Saffarpour A, Fekrazad R, Heibati MN, Bahador A, Saffarpour A, Rokn AR, et al. Bactericidal effect of erbium-doped yttrium aluminum garnet laser and photodynamic therapy on Aggregatibacter actinomycetemcomitans biofilm on implant surface. Int J Oral Maxillofac Implants. 2016 May-Jun;31(3):e71-8.
36. Kubasiewicz-Ross P, Hadzik J, Gedrange T, Dominiak M, Jurczyszyn K, Pitułaj A, et al.

Antimicrobial efficacy of different decontamination methods as tested on dental implants with various types of surfaces. Med Sci Monit. 2020 Feb;26:e920513.
37. Vaddamanu SK, Vyas R, Kavita K, Sushma R, Rani RP, Dixit A, et al. An in vitro study to compare dental laser with other treatment modalities on biofilm ablation from implant and tooth surfaces. J Pharm Bioallied Sci. 2022 Jul;14(Suppl 1):S530-3.
38. Giannelli M, Pini A, Formigli L, Bani D. Comparative in vitro study among the effects of different laser and LED irradiation protocols and conventional chlorhexidine treatment for deactivation of bacterial lipopolysaccharide adherent to titanium surface. Photomed Laser Surg. 2011 Aug;29(8):573-80.
39. Birang E, Birang R, Narimani T, Tolouei A, Fekrazad R. Investigation of the antibacterial effect of laser irradiation and chemical agent on human oral biofilms contaminated titanium discs. Photodiagnosis Photodyn Ther. 2019 Mar;25:259-64.
40. Birang R, Shakerian K, Birang E, Narimani T, Naghsh N, Fekrazad R. Comparison of antimicrobial effect of several decontaminating methods on contaminated Titanium discs. Dent Res J (Isfahan). 2022 Dec;19:111.
41. Gümüş KÇ, Ustaoğlu G, Kara L, Ercan E, Albayrak Ö, Tunali M. Nano-hydroxyapatite airborne-particle abrasion system as an alternative surface treatment method on intraorally contaminated titanium discs. Int J Periodontics Restorative Dent. 2020 Jul/Aug;40(4):e179-87.
42. El Chaar E, Almogahwi M, Abdalkader K, Alshehri A, Cruz S, Ricci J. Decontamination of the infected implant surface: A scanning electron microscope study. Int J Periodontics Restorative Dent. 2020 May-Jun;40(3):395-401.
43. Otsuki M, Wada M, Yamaguchi M, Kawabata S, Maeda Y, Ikebe K. Evaluation of decontamination methods of oral biofilms formed on screw-shaped, rough and machined surface implants: an ex vivo study. Int J Implant Dent. 2020 Apr;6(1):18.
44. Kormas I, Pedercini C, Pedercini A, Raptopoulos M, Alassy H, Wolff LF. Peri-implant diseases: diagnosis, clinical, histological, microbiological characteristics and treatment strategies. A narrative review. Antibiotics (Basel). 2020 Nov;9(11):835.
45. Mellado-Valero A, Buitrago-Vera P, Solá-Ruiz MF, Ferrer-García JC. Decontamination of dental implant surface in peri-implantitis treatment: a literature review. Med Oral Patol Oral Cir Bucal. 2013 Nov;18(6):e869-76.
46. Dhaliwal JS, Abd Rahman NA, Ming LC, Dhaliwal SKS, Knights J, Albuquerque Junior RF. Microbial biofilm decontamination on dental implant surfaces: A mini review. Front Cell Infect Microbiol. 2021 Oct;11:736186.
47. Ramanauskaite A, Schwarz F, Cafferata EA, Sahrmann P. Photo/mechanical and physical implant surface decontamination approaches in conjunction with surgical peri-implantitis treatment: A systematic review. J Clin Periodontol. 2023 Jun;50 Suppl 26:317-35.