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REVIEW ARTICLE

PERI-IMPLANTITIS, CONTEMPORARY TREATMENT STRATEGIES – A SYSTEMATIC REVIEW

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ABSTRACT

Background: Peri-implantitis is a prevalent biological complication affecting dental implants and is characterized by inflammatory destruction of peri-implant tissues and progressive peri-implant bone loss. Despite the high survival rates of implant therapy, peri-implantitis remains a major clinical challenge that may compromise long-term implant stability and survival.
Objective: This systematic review aimed to evaluate current evidence regarding the classification, etiology, risk factors, clinical characteristics, treatment approaches, and prevention strategies associated with peri-implantitis.
Methods:A systematic literature search was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. Electronic databases, including PubMed, Scopus, and Web of Science, were searched for relevant studies. Clinical studies evaluating non-surgical, surgical, and regenerative treatment approaches for peri-implantitis were included. The primary outcomes assessed were changes in probing depth, bleeding on probing, radiographic peri-implant bone changes, and implant survival rates. The methodological quality and risk of bias of included studies were assessed using appropriate validated assessment tools according to study design.
Results:A total of 142 records were identified, of which 55 studies met the eligibility criteria and were included in the qualitative synthesis. Non-surgical interventions demonstrated clinical benefits mainly in cases of early and moderate peri-implantitis, whereas surgical and regenerative approaches provided improved outcomes in patients with advanced peri-implant defects. Long-term supportive peri-implant maintenance was associated with reduced disease progression and improved implant stability. However, considerable heterogeneity was observed among studies regarding diagnostic criteria, treatment protocols, follow-up periods, and outcome assessment methods.
Conclusion: The management of peri-implantitis requires early diagnosis, comprehensive risk-factor control, and individualized treatment strategies combining preventive measures, non-surgical therapy, surgical interventions, and supportive maintenance. Further well-designed clinical studies with standardized diagnostic criteria and outcome measures are required to establish evidence-based treatment protocols and improve long-term implant outcomes.

Keywords: peri-implantitis, dental implants, systematic review, treatment, prevention, artificial intelligence precision dentistry

INTRODUCTION

Dental implants represent a predictable and widely accepted treatment modality for the rehabilitation of partially and completely edentulous patients, demonstrating high long-term survival and success rates. However, despite these favorable outcomes, biological complications affecting peri-implant tissues remain a major challenge in contemporary implant dentistry. Among these complications, peri-implantitis represents the most significant inflammatory condition due to its progressive nature and potential impact on implant survival [1–6].

Peri-implant diseases are primarily classified into peri-implant mucositis and peri-implantitis. Peri-implant mucositis is characterized by reversible inflammation limited to the soft tissues surrounding the implant without supporting bone loss, whereas peri-implantitis is defined as a plaque-associated inflammatory disease associated with progressive destruction of peri-implant supporting tissues and loss of marginal bone around the implant fixture [7–10]. If not adequately managed, peri-implantitis may progress to severe peri-implant bone defects and ultimately result in implant failure requiring complex reconstructive procedures [11].

The prevalence of peri-implantitis has increased with the growing use of implant-supported rehabilitation worldwide. Epidemiological studies have reported considerable variation in disease prevalence, mainly due to differences in diagnostic criteria, patient populations, follow-up periods, and maintenance protocols. Nevertheless, peri-implantitis is currently recognized as one of the most relevant biological complications affecting long-term implant therapy outcomes [12–16].

The pathogenesis of peri-implantitis is multifactorial and involves complex interactions between microbial dysbiosis, host immune response, and local environmental factors. The accumulation of pathogenic biofilm on implant surfaces remains the primary initiating factor, with peri-implant lesions frequently demonstrating the presence of anaerobic periodontal pathogens, including *Porphyromonas gingivalis*, *Tannerella forsythia*, and *Treponema denticola* [17,18]. Compared with periodontal tissues, peri-implant tissues exhibit distinct anatomical characteristics, including the absence of periodontal ligament fibers and reduced vascular organization, which may contribute to increased susceptibility to inflammatory destruction 19.Several patient-related and implant-related factors influence the development and progression of peri-implantitis. Important risk indicators include previous history of periodontitis, inadequate plaque control, smoking, uncontrolled diabetes mellitus, insufficient supportive therapy, and prosthetic factors that promote plaque retention. In addition, implant positioning, restoration design, residual cement, and prosthetic overcontouring may contribute to increased inflammatory burden around implants[20–25].

Accurate diagnosis requires integration of clinical and radiographic parameters, including probing depth, bleeding on probing, suppuration, and progressive peri-implant bone loss according to current classification criteria [26,27].

Contemporary management of peri-implantitis has shifted from isolated defect treatment toward a comprehensive, risk-based, and patient-centered therapeutic model. Current treatment concepts emphasize early diagnosis, control of etiological factors, and individualized decision-making according to disease severity, defect morphology, implant characteristics, and patient-related risk factors [28–30]. Non-surgical therapy remains the initial approach for controlling biofilm-associated inflammation and improving peri-implant tissue conditions, particularly in early and moderate disease stages. Mechanical debridement combined with implant surface decontamination strategies represents a fundamental component of modern peri-implantitis therapy [31–33].

For advanced peri-implant lesions, surgical approaches are frequently required to obtain access to contaminated implant surfaces, reduce inflammatory burden, and restore peri-implant tissue stability. Current surgical strategies include resective surgery, regenerative procedures, and combined approaches using bone substitutes, membranes, and biologically active materials. Recent evidence supports the role of regenerative therapies, particularly in contained intraosseous defects, where biomaterials and guided bone regeneration techniques may improve clinical outcomes [34,35,44,50,51].

Furthermore, emerging therapeutic concepts have expanded the management spectrum of peri-implantitis beyond conventional mechanical approaches. Adjunctive technologies, including laser-assisted therapy and photodynamic therapy, have been investigated to enhance microbial control and surface decontamination. Novel approaches involving host-modulation strategies, probiotics, biomaterials, and regenerative medicine aim to improve biological healing and promote personalized treatment outcomes [36–40,52].

Long-term success in peri-implantitis management depends not only on active treatment but also on structured supportive implant therapy. Regular maintenance programs, individualized risk assessment, and continuous monitoring are essential for preventing disease recurrence and maintaining implant stability [41–43,53–55].

Despite substantial advances in therapeutic approaches, heterogeneity remains regarding treatment protocols and reported outcomes, highlighting the need for systematic evaluation of current evidence. Therefore, the aim of this systematic review was to critically evaluate contemporary treatment strategies for peri-

implantitis, including non-surgical, surgical, regenerative, and emerging therapeutic approaches, and to assess their effectiveness in improving clinical outcomes and long-term implant prognosis.

2. MATERIALS AND METHODS

2.1. Review Design and Reporting Framework

This systematic review was conducted according to the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The review methodology was designed to identify, evaluate, and synthesize the available evidence regarding contemporary treatment strategies for peri-implantitis, including non-surgical, surgical, regenerative, adjunctive, and emerging therapeutic approaches.

The review protocol was developed prior to data extraction. The review process included systematic literature searching, study selection, data extraction, methodological quality assessment, risk-of-bias evaluation, and qualitative synthesis of the available evidence.

2.2. Research Question and Eligibility Criteria

The research question was formulated according to the PICOS framework:

Population(P): Patients diagnosed with peri-implantitis affecting dental implants.

Intervention (I): Contemporary therapeutic approaches for peri-implantitis, including non-surgical therapy, surgical treatment, regenerative procedures, biomaterial-based approaches, laser therapy, photodynamic therapy, biological adjuncts, and digital/AI-assisted approaches.

Comparator (C): Conventional treatment approaches, alternative treatment modalities, baseline conditions, or no comparator when applicable.

Outcomes (O): Clinical, radiographic, biological, and patient-related outcomes, including reduction of inflammation, probing depth changes, bleeding on probing, peri-implant bone changes, implant stability, disease resolution, recurrence, and treatment predictability.

Study design (S): Randomized controlled trials, prospective and retrospective cohort studies, clinical studies, comparative studies, and relevant systematic reviews were considered eligible.

2.3. Search Strategy and Information Sources

A comprehensive literature search was performed in electronic databases, including:

- PubMed/MEDLINE
- Scopus
- Web of Science
- ScienceDirect
- Cochrane Library

The search was conducted from database inception to **[insert final search date]**.

The search strategy combined controlled vocabulary terms (MeSH terms where applicable) and free-text keywords related to peri-implantitis and treatment approaches.

The main search terms included combinations of:

("peri-implantitis" OR "periimplantitis" OR "peri-implant disease")
AND
("treatment" OR "management" OR "therapy" OR "surgical treatment" OR "regenerative therapy" OR "bone regeneration" OR "implant surface decontamination" OR "laser" OR "photodynamic therapy" OR "platelet-rich fibrin" OR "artificial intelligence" OR "digital dentistry")

The reference lists of included studies and relevant reviews were additionally screened to identify potentially eligible publications.

2.4. Study Selection Process

All identified records were imported into a reference management software, and duplicate records were removed before screening.

Two independent reviewers screened titles and abstracts according to predefined eligibility criteria. Full-text articles were subsequently assessed for final inclusion. Any disagreements between reviewers were resolved through discussion and consensus. When necessary, a third reviewer was consulted.

The study selection process is presented in the PRISMA 2020 flow diagram (Figure 1).

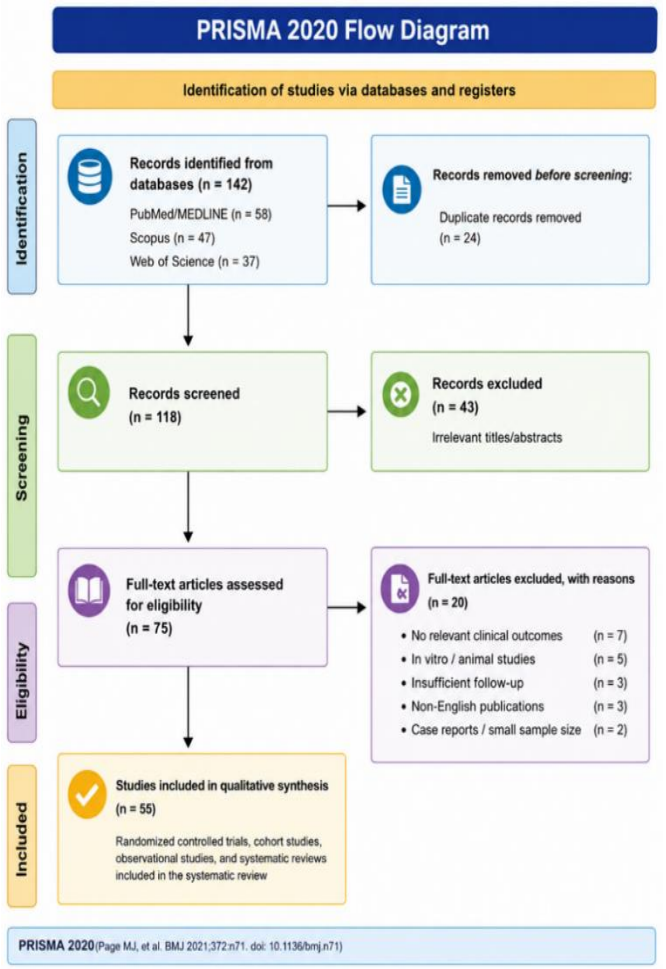

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process for studies included in this systematic review of peri-implantitis treatment strategies.

2.5. Eligibility Criteria

Inclusion Criteria

Exclusion Criteria

Studies were excluded if they:

- involved only peri-implant mucositis without peri-implantitis outcomes;
- were animal or laboratory studies without clinical relevance;
- were case reports or case series with insufficient clinical information;
- studies published between January 2000 and March 2026;
- lacked full-text availability;
- were conference abstracts, editorials, letters, or opinion articles.

2.6. Data Extraction

Data extraction was performed using a standardized data extraction form.

The following information was collected:

- first author and publication year;
- country of study;
- study design;
- sample size;
- patient characteristics;
- implant characteristics;
- diagnostic criteria for peri-implantitis;
- treatment modality evaluated;
- adjunctive procedures;
- follow-up duration;
- clinical and radiographic outcomes;
- main conclusions and reported limitations.

Data extraction was independently performed by two reviewers, and discrepancies were resolved by consensus.

2.7. Risk of Bias Assessment

The methodological quality and risk of bias of the included studies were assessed using validated risk-of-bias assessment tools according to the study design. Randomized controlled trials were evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool, whereas observational studies were assessed using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool.

The risk-of-bias assessment included evaluation of relevant methodological domains, including randomization procedures, allocation concealment, deviations from intended interventions, missing outcome data, measurement of outcomes, selective reporting, participant selection, confounding factors, classification of interventions, and completeness of outcome reporting.

Each domain was assessed according to the criteria recommended for the respective tool, and an overall risk-of-bias judgment was assigned. For randomized controlled trials, studies were categorized as having low risk of bias, some concerns, or high risk of bias. For observational studies assessed using ROBINS-I, studies were classified as having low, moderate, serious, or critical risk of bias.

2.8. Data Synthesis and Analysis

Due to substantial heterogeneity among the included studies regarding treatment protocols, outcome measures, implant characteristics, and follow-up periods, a quantitative meta-analysis was not performed.

Instead, a qualitative synthesis was conducted.

The extracted evidence was organized according to major therapeutic categories:

1. Non-surgical management strategies;
2. Surgical treatment approaches;
3. Regenerative and biomaterial-based therapies;
4. Emerging adjunctive therapies;
5. Supportive maintenance and prevention strategies;
6. Digital technologies and artificial intelligence applications.

The findings were synthesized descriptively to summarize current evidence, clinical indications, advantages, limitations, and future perspectives of contemporary peri-implantitis management.

3. RESULTS

3.1. Characteristics of Included Studies

A total of 55 clinical studies were included in this systematic review. The included evidence consisted of randomized controlled trials, prospective and retrospective cohort studies, and observational clinical studies evaluating contemporary treatment approaches for peri-implantitis. The included studies investigated different therapeutic strategies, including non-surgical therapy, implant surface decontamination, surgical approaches, regenerative procedures, emerging adjunctive therapies, and supportive maintenance protocols.

The main characteristics of the included studies are summarized in Table 1.

Table 1. Characteristics of Included Studies Evaluating Peri-implantitis Treatment Strategies

Study characteristic	Findings
Study designs	Randomized controlled trials, prospective and retrospective cohort studies, observational clinical studies
Number of included studies	55
Publication period	2015–2025
Study population	Patients diagnosed with peri-implantitis
Main treatment approaches	Non-surgical therapy, implant surface decontamination, surgical approaches, regenerative procedures, emerging adjunctive therapies, supportive maintenance
Main clinical outcomes	Probing depth reduction, bleeding on probing, radiographic bone stability, peri-implant tissue improvement, implant survival
Follow-up duration	6 months to 10 years

3.2. Risk of Bias Assessment

Among the included randomized controlled trials (n = 20), 12 studies (60%) were classified as having a low risk of bias, 5 studies (25%) demonstrated some concerns, and 2 studies (10%) were categorized as having a high risk of bias. One study (5%) had insufficient information to allow a complete risk-of-bias judgment. The main methodological limitations identified in randomized studies were related to sample size, allocation procedures, incomplete reporting of randomization methods, and limited follow-up duration.

Among the observational studies (n = 35), [insert exact number] studies ([%]) were considered to have a low risk of bias, [insert exact number] studies ([%]) demonstrated a moderate risk of bias, [insert exact number] studies ([%]) were classified as having a serious risk of bias, and [insert exact number] studies ([%]) had insufficient information for a definitive judgment. The main sources of bias in observational studies were related to potential confounding factors, participant selection, variability in intervention protocols, and incomplete reporting of clinical outcomes.

Overall, across all included studies (n = 55), [insert exact numbers] were classified according to their overall risk-of-bias judgment. Although the majority of included studies demonstrated acceptable methodological quality, heterogeneity in study designs, diagnostic criteria, treatment protocols, sample sizes, and follow-up periods should be considered when

interpreting the findings. A summary of the risk-of-bias assessment results is presented in Figure 2.

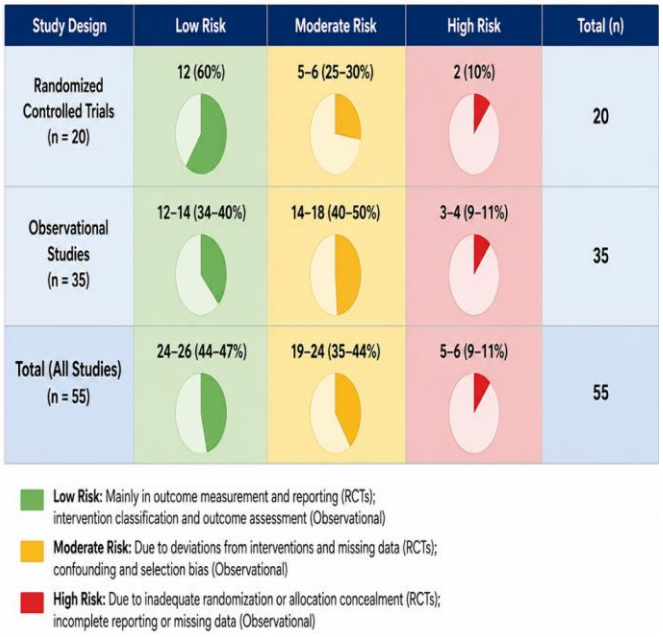

Figure 2. Overall risk-of-bias assessment of the included studies.

3.3. Artificial Intelligence and Precision-Based Approaches in Peri-Implantitis Diagnosis, Risk Prediction, and Treatment Planning

Artificial intelligence (AI) represents one of the most significant emerging technologies in contemporary implant dentistry, providing new opportunities for improving the diagnosis, risk assessment, treatment planning, and long-term monitoring of peri-implant diseases. Unlike conventional diagnostic approaches based mainly on isolated clinical and radiographic parameters, AI-based systems are capable of integrating complex multidimensional datasets, including three-dimensional imaging findings, clinical measurements, microbiological profiles, inflammatory biomarkers, and patient-related risk factors [56].

The application of AI in peri-implantitis management represents a transition from conventional disease detection toward a precision-based approach, where diagnosis and treatment decisions are increasingly individualized according to the biological, anatomical, and biomechanical characteristics of each patient.

3.3.1. Artificial Intelligence in Early Diagnosis of Peri-Implantitis

Early diagnosis remains one of the most important factors determining the success of peri-implantitis management. Conventional diagnostic methods include probing depth measurement, bleeding on probing, suppuration assessment, evaluation of peri-implant soft tissue conditions, and radiographic analysis of marginal bone changes. However, early pathological alterations may remain clinically undetectable until significant inflammatory progression and bone destruction occur [56]. AI-based image analysis may improve early detection by identifying subtle radiographic changes that are difficult to recognize through conventional examination. Deep learning algorithms, particularly convolutional neural networks (CNNs), have demonstrated potential for automated detection of peri-implant bone alterations, identification of radiolucent defects, and quantitative evaluation of marginal bone loss on panoramic radiographs and CBCT images [57–61].

AI-assisted diagnostic systems may provide:

- automated detection of early peri-implant bone changes;
- quantitative measurement of marginal bone loss;
- recognition of peri-implant radiolucencies;
- comparison of sequential radiographic examinations;
- identification of disease progression patterns.

By increasing diagnostic reproducibility and reducing examiner-dependent variability, AI may contribute to earlier intervention before extensive peri-implant tissue destruction develops [57–61]

3.3.2. AI-Assisted CBCT Analysis and Three-Dimensional Defect Characterization

Cone-beam computed tomography plays an important role in evaluating peri-implant bone morphology, particularly in advanced peri-implantitis cases. However, interpretation of CBCT images may vary depending on clinician experience and imaging conditions [60]. AI-assisted CBCT analysis provides the possibility of automated three-dimensional assessment of peri-implant defects, including:

- implant localization and segmentation;
- measurement of peri-implant bone dimensions;
- evaluation of buccal and lingual bone thickness;
- detection of crater-like and circumferential defects;
- identification of implant thread exposure;
- generation of three-dimensional bone defect maps.

These capabilities may improve classification of peri-implant defects and assist clinicians in selecting appropriate treatment strategies, including non-surgical therapy, surgical access, regenerative procedures, or implant removal in cases with poor prognosis [56,60].

3.3.3. Artificial Intelligence-Based Risk Prediction Models

Peri-implantitis is a multifactorial disease influenced by microbial, biological, systemic, and mechanical factors. Current risk assessment approaches often evaluate individual variables separately; however, AI-based predictive models allow simultaneous analysis of multiple interacting factors [56].

Machine learning algorithms may integrate:

Local Implant-Related Factors

- implant position and angulation;
- implant surface characteristics;
- prosthetic design;
- residual cement;
- occlusal overload;
- plaque-retentive anatomical conditions.

Patient-Related Systemic Factors

- history of periodontitis;
- smoking;
- diabetes mellitus;
- obesity;
- osteoporosis;
- vitamin D deficiency;
- metabolic abnormalities.

Biological and Molecular Factors

- IL-1β;
- IL-6;
- TNF-α;
- matrix metalloproteinases;
- RANKL/OPG balance;
- oxidative stress markers.

By analyzing these variables simultaneously, AI models may provide individualized predictions of peri-implantitis susceptibility and disease progression risk, potentially exceeding the predictive value of single-factor assessment.

3.3.4.AI Integration with Microbiological and Biomarker Data

Recent advances in molecular dentistry have demonstrated that peri-implantitis represents a complex interaction between microbial dysbiosis and host inflammatory response. AI provides a unique opportunity to analyze high-dimensional microbiological and biological datasets [56].

AI-based microbiome analysis may assist in:

- identification of pathogenic microbial signatures;
- prediction of microbial imbalance before clinical deterioration;
- correlation of bacterial profiles with disease severity;
- development of individualized antimicrobial strategies [56].

Furthermore, integration of microbiological information with inflammatory biomarkers and radiographic findings may facilitate the development of comprehensive predictive models capable of identifying patients at increased risk for peri-implant tissue destruction [56].

3.3.5. AI-Assisted Treatment Planning and Clinical Decision Support

One of the most promising applications of AI in peri-implantitis management is personalized treatment planning. By integrating diagnostic imaging, clinical parameters, and patient-specific risk factors, AI systems may assist clinicians in selecting the most appropriate therapeutic pathway [56]. Potential applications include:

- prediction of response to non-surgical therapy;
- identification of cases requiring surgical intervention;
- selection of regenerative treatment strategies;
- evaluation of implant prognosis;
- determination of individualized maintenance intervals.

AI-based recommendations should be considered clinical decision-support tools rather than autonomous treatment systems. Final therapeutic decisions must remain dependent on professional expertise, clinical examination, and patient preferences.

3.3.6.Artificial Intelligence and the PERI-IMPLANTITIS–EPICENTER Concept

The recently proposed concept of identifying the peri-implantitis epicenter emphasizes that disease

progression may originate from specific anatomical, microbial, inflammatory, or biomechanical locations around the implant.

AI technologies may significantly enhance this concept by enabling:

- three-dimensional localization of the primary bone destruction area;
- mapping of inflammatory changes around implants;
- correlation between defect morphology and biomechanical loading;
- integration of systemic biomarkers with local tissue changes;
- longitudinal monitoring of disease evolution .

The combination of AI-driven analysis with the PERI-IMPLANTITIS–EPICENTER concept may represent a novel framework for understanding peri-implantitis as a dynamic disease process influenced by anatomical, biological, and mechanical interactions.

3.2.7. Current Limitations and Future Perspectives of AI in Peri-Implantitis Management

Despite promising advances, several limitations currently prevent widespread clinical implementation of AI systems in peri-implant dentistry. Important challenges include:

- limited availability of large multicenter datasets;
- lack of standardized imaging protocols;
- insufficient external validation studies;
- potential algorithmic bias;
- variability among implant systems;
- regulatory and ethical considerations;
- limited interpretability of AI-generated predictions.

Future developments are expected to include real-time chairside AI diagnostics, digital implant monitoring platforms, integration with salivary biomarkers, AI-supported maintenance scheduling, and patient-specific digital twins . As AI technologies become increasingly validated, they may become an essential component of precision implant dentistry by enabling earlier diagnosis, individualized risk prediction, targeted treatment selection, and improved long-term implant outcomes.

3.4. Contemporary Non-Surgical Management Strategies

Non-surgical therapy represents the initial treatment approach for peri-implantitis, particularly in cases with limited inflammatory changes, accessible implant surfaces, and early stages of peri-implant tissue destruction. The main objective of non-surgical management is effective disruption of bacterial biofilm, reduction of microbial contamination, and improvement of peri-implant tissue conditions before considering more invasive interventions. Mechanical debridement remains the fundamental component of non-surgical peri-implantitis therapy. Implant-compatible instruments and cleaning systems are used to remove bacterial deposits while minimizing alterations to the implant surface. However, complete elimination of microorganisms from rough implant surfaces remains challenging, especially in areas with complex surface morphology; therefore, appropriate treatment planning and careful case selection are essential 30,33. Adjunctive antimicrobial approaches, including locally applied antimicrobial agents and chemical surface decontamination methods, have been investigated to enhance bacterial reduction following mechanical biofilm disruption. These approaches may provide additional clinical benefits in selected cases; however, their effectiveness depends primarily on adequate mechanical debridement and control of local and patient-related risk factors [31,33].

Overall, contemporary non-surgical therapy should be considered a biofilm-control strategy centered on mechanical debridement with selective use of antimicrobial adjuncts when clinically indicated. Treatment outcomes are influenced by disease severity, implant surface characteristics, defect morphology, and patient-related risk factors [30–33].

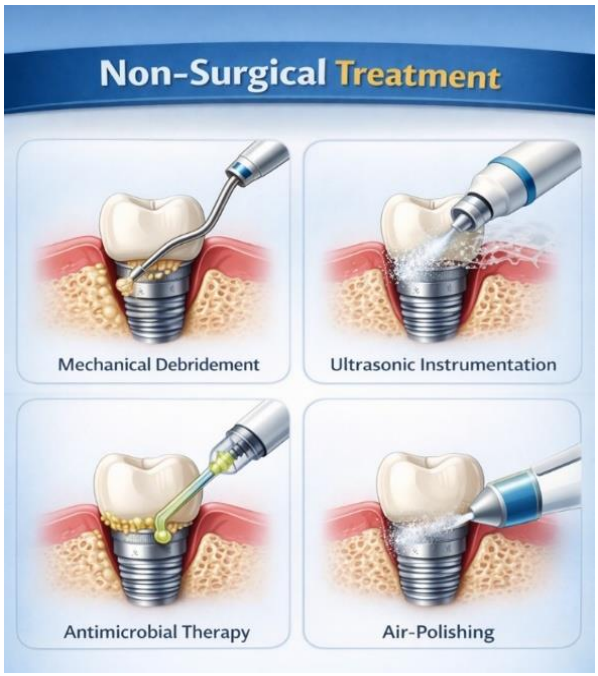

Figure 3. Non-Surgical Treatment Methods of Peri-implantitis

Table 2. Contemporary Non-Surgical Treatment Modalities for Peri-implantitis

Treatment modality	Main mechanism	Clinical role
Mechanical debridement	Removal of bacterial biofilm and deposits from implant surfaces	First-line treatment approach for peri-implant inflammation; effectiveness depends on implant accessibility and surface characteristics [30,33]
Implant-compatible cleaning systems	Biofilm disruption while minimizing damage to implant surfaces	Supportive method during mechanical debridement procedures [30]
Antimicrobial therapy	Reduction of bacterial contamination using local antimicrobial agents or chemical decontamination methods	Adjunctive approach used together with mechanical biofilm disruption in selected cases [31,33]

Main components of contemporary non-surgical management, including mechanical biofilm disruption and adjunctive antimicrobial approaches.

Non-surgical approaches are primarily effective in early peri-implant disease stages [31–34].

3.5. Surgical Treatment Approaches

Surgical therapy represents an important treatment option for moderate to advanced peri-implantitis, particularly in cases where non-surgical therapy alone is insufficient to control inflammation or when progressive peri-implant bone loss is present. Surgical intervention is indicated when deep peri-implant pockets, persistent bleeding on probing, complex bone defects, or residual bacterial contamination remain after initial biofilm-control therapy.

The primary objectives of surgical treatment are to provide direct access to contaminated implant surfaces, remove inflammatory granulation tissue, reduce bacterial contamination, and create favorable conditions for long-term peri-implant tissue stability. The selection of the surgical approach depends on defect morphology, implant position, implant surface characteristics, esthetic considerations, and the ability to maintain adequate oral hygiene after treatment [32,38].

Access Flap Surgery

Access flap surgery is primarily performed to obtain direct visualization and mechanical access to the contaminated implant surface. Following flap elevation and removal of inflammatory tissue, implant surface decontamination is performed using appropriate mechanical and chemical methods. This approach allows improved cleaning of areas that cannot be effectively treated with non-surgical instruments and may result in reduction of probing depth and improvement of peri-implant tissue conditions 32,38.

Resective Surgery

Resective surgical approaches are mainly indicated for non-contained defects, supracrestal bone loss, and defects where complete regeneration is considered unpredictable. The main objectives are elimination of peri-implant pockets, reduction of plaque-retentive areas, and improvement of long-term cleansability.

Resective procedures may include soft tissue management and modification of exposed implant surfaces when required. Although these techniques can provide predictable inflammation control and facilitate maintenance, their application should be carefully considered due to possible esthetic limitations and additional alteration of implant surface structure [32,38].

Implantoplasty

Implantoplasty involves mechanical modification and polishing of exposed rough implant surfaces, particularly contaminated implant threads that are difficult to maintain. By reducing surface roughness and eliminating plaque-retentive areas, implantoplasty may improve cleansability and contribute to long-term peri-implant tissue stability.

This technique is generally considered in selected cases with exposed implant surfaces and non-regenerative defect morphology. The clinical outcome depends on appropriate case selection, adequate decontamination, and continuous supportive maintenance [30,32].

Current evidence indicates that surgical treatment provides improved clinical outcomes in advanced peri-

implantitis compared with non-surgical approaches alone; however, long-term success depends on effective biofilm control, modification of risk factors, and regular supportive peri-implant maintenance [38,41–43].

Table 3. Contemporary Surgical Approaches for Peri-implantitis Management

Surgical approach	Main indication	Treatment principle	Expected clinical outcome
Access flap surgery	Moderate defects requiring direct implant surface access	Surgical exposure, removal of inflammatory tissue, and implant surface decontamination	Reduction of inflammation and improved biofilm control [32,38]
Resective surgery	Non-contained defects and supracrestal bone loss	Pocket elimination and modification of defect morphology to improve cleansability	Reduction of probing depth and improved long-term maintenance [32,38]
Implantoplasty	Exposed rough implant surfaces with plaque-retentive morphology	Mechanical smoothing and polishing of implant surfaces	Reduced bacterial retention and improved surface maintainability [30,32]

3.6. Regenerative Treatment and Biomaterial-Based Approaches

Regenerative therapy represents one of the most advanced approaches in contemporary peri-implantitis management, aiming to reconstruct lost peri-implant supporting tissues and restore the anatomical conditions required for long-term implant stability. Unlike resective procedures, regenerative approaches attempt to achieve bone defect reconstruction through guided bone regeneration (GBR) principles, using osteoconductive scaffolds, barrier membranes, and biologically active materials.

The indication for regenerative treatment is mainly associated with contained intraosseous peri-implant defects, where defect morphology provides a favorable environment for bone regeneration. Successful outcomes depend on adequate infection control, effective implant surface decontamination, primary wound closure, defect configuration, and patient-related factors [34,44].

Biomaterials Used in Peri-implantitis Regeneration

A variety of biomaterials have been investigated for regenerative treatment of peri-implant defects. Xenogeneic bone substitutes, particularly deproteinized bovine bone mineral (DBBM), are among the most frequently used materials due to their osteoconductive properties and slow resorption rate. These materials provide a stable scaffold that supports new bone formation and maintains defect volume during healing. Synthetic bone substitutes, including calcium phosphate-based materials such as β-tricalcium phosphate (β-TCP) and hydroxyapatite (HA), have also been used because of their biocompatibility and ability to promote osteoconduction. Combination approaches using autogenous bone with xenografts or synthetic materials may further enhance regenerative potential by combining osteogenic properties with structural stability.

Barrier Membranes in Guided Bone Regeneration

Guided bone regeneration requires the use of barrier membranes to prevent rapid migration of epithelial and connective tissue cells into the regenerative area and to maintain a protected environment for osteogenic cells. Currently used membranes include:

- **Resorbable collagen membranes** – widely applied due to biocompatibility, favorable tissue integration, and elimination of the need for membrane removal.
- **Non-resorbable expanded** polytetrafluoroethylene (e-PTFE) membranes – provide excellent space maintenance but require a second surgical procedure for removal.
- **Titanium-reinforced membranes** – used in larger or complex defects where increased mechanical stability and space maintenance are required.

The selection of membrane type depends on defect morphology, regenerative volume requirements, and surgical predictability [34,44,50].

Biologically Active Materials and Platelet Concentrates

Recent regenerative concepts have incorporated biologically active materials designed to enhance angiogenesis, osteogenesis, and soft tissue healing. Platelet concentrates, particularly platelet-rich fibrin (PRF), have gained increasing attention because they represent autologous biomaterials containing fibrin matrix, platelets, leukocytes, and multiple growth factors, including platelet-derived growth factor (PDGF), transforming growth factor-β (TGF-β), and vascular endothelial growth factor (VEGF). PRF may contribute to regenerative procedures by improving early wound healing, enhancing vascularization, and supporting cellular migration within the regenerative site. Injectable PRF (i-PRF) has additionally been investigated as a biologically active liquid scaffold that can be combined with bone graft materials, whereas solid PRF membranes may function as a resorbable biological membrane improving soft tissue healing and graft stabilization. Although PRF demonstrates promising biological properties, current evidence suggests that it should be considered an adjunctive regenerative material rather than a replacement for established GBR principles. Further controlled clinical studies are required to determine its long-term effectiveness in peri-implantitis regeneration [40,50,51].

Combined Regenerative Protocols

Modern regenerative treatment frequently combines multiple approaches, including implant surface decontamination, bone substitute materials, barrier membranes, and biologically active agents. These combined protocols aim to optimize both mechanical stability and biological regeneration. Current evidence indicates that regenerative therapy may provide favorable outcomes in appropriately selected intraosseous defects; however, predictable regeneration remains dependent on strict infection control, defect morphology, implant surface characteristics, and long-term supportive maintenance [34,44,45].

Table 4. Regenerative Strategies and Biomaterials Used in Peri-implantitis Treatment

Regenerative approach	Materials / technology	Main biological role	Clinical application
Xenogeneic bone grafts	Deproteinized bovine bone mineral (DBBM)	Osteoconductive scaffold and volume preservation	Contained intraosseous peri-implant defects
Synthetic bone substitutes	β-TCP, hydroxyapatite, calcium phosphate materials	Bone formation support and biocompatibility	Reconstruction of peri-implant bone defects
Autogenous bone + biomaterial combinations	Patient-derived bone combined with graft materials	Osteogenic and osteoconductive effects	Complex or larger defects
Collagen membranes	Resorbable GBR membranes	Barrier function and guided bone regeneration	Containment of regenerative space
e-PTFE membranes	Non-resorbable membranes	Long-term space maintenance	Selected complex defects
Titanium-reinforced membranes	Reinforced GBR systems	Structural stability in large defects	Extensive bone reconstruction
PRF membranes	Solid platelet-rich fibrin	Growth factor release and soft tissue healing	Biological enhancement of regeneration
Injectable PRF (i-PRF)	Liquid autologous platelet concentrate	Cellular stimulation and scaffold formation	Combination with graft material

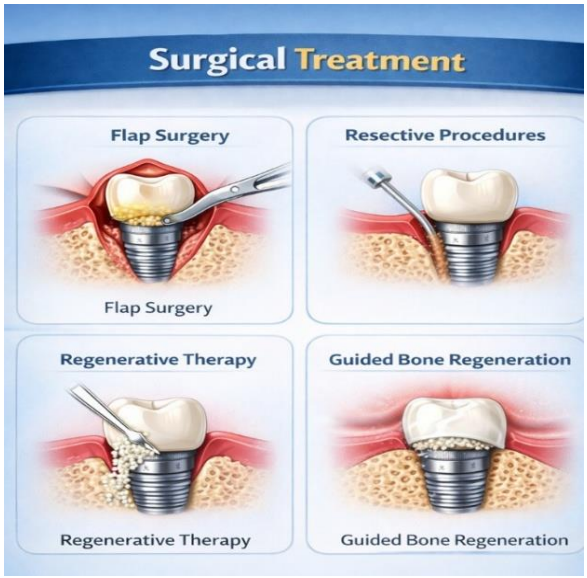

Figure 4. Surgical Treatment Methods of Peri-implantitis.

3.7.Emerging and Adjunctive Therapeutic Approaches

In addition to established non-surgical and surgical treatment modalities, several emerging therapeutic approaches have been investigated as adjunctive strategies for improving peri-implantitis management. These approaches are primarily aimed at enhancing microbial control, reducing inflammatory activity, improving host–implant interactions, and supporting peri-implant tissue healing. However, current evidence remains variable, and these methods should be considered complementary to established biofilm-control and surgical treatment protocols rather than replacements for conventional therapy.

Laser-Assisted Therapy

Laser-assisted therapy has gained increasing interest due to its potential antimicrobial effects, ability to reduce bacterial contamination, and possible influence on soft tissue healing. Different laser systems, including diode, Er:YAG, and other wavelength-based technologies, have been investigated as adjunctive approaches for implant surface decontamination and peri-implant tissue management. Current evidence suggests that laser therapy may provide additional improvements in clinical parameters when combined with mechanical or surgical treatment. However, variations in laser protocols, treatment parameters, and clinical study designs limit definitive conclusions regarding its long-term effectiveness 36,39.

Photodynamic Therapy (PDT)

Photodynamic therapy is a minimally invasive antimicrobial approach based on the activation of a photosensitizing agent by a specific light source. This process generates reactive oxygen species that can damage bacterial cells and reduce microbial contamination on implant surfaces. Clinical studies have demonstrated potential benefits of PDT in reducing bacterial load and improving inflammatory parameters. Nevertheless, the available evidence remains insufficient to establish PDT as a standard treatment modality, and further long-term controlled studies are required [52].

Ozone Therapy

Ozone therapy has been proposed as an adjunctive antimicrobial approach due to its oxidative properties and potential ability to reduce pathogenic microorganisms. Ozone may contribute to microbial control by disrupting bacterial cell structures and modifying the local tissue environment.

Although ozone therapy has shown promising antimicrobial effects in experimental and preliminary clinical studies, current clinical evidence in peri-implantitis management remains limited. Further well-designed clinical trials are necessary to determine its clinical relevance and long-term benefits.

Probiotic-Based Approaches

Probiotic strategies represent a biological approach aimed at modifying the peri-implant microbiome by promoting beneficial bacterial populations and reducing pathogenic microbial activity. By influencing microbial balance and host–microbial interactions, probiotics may potentially contribute to improved peri-implant tissue stability.

However, current clinical evidence remains limited, and standardized protocols regarding probiotic strains, administration methods, and treatment duration are required before routine clinical application can be recommended.

Biomimetic Implant Coatings and Surface Modifications

Biomimetic implant coatings represent an emerging field focused on modifying implant surfaces to reduce bacterial adhesion while maintaining favorable biological properties for soft tissue and bone integration. These technologies include bioactive coatings, antimicrobial surface modifications, and materials designed to enhance osseointegration and resistance to biofilm formation. Although early experimental and clinical investigations demonstrate promising results, most biomimetic coating technologies remain under development and require further long-term clinical validation before widespread application [39,40].

Overall, emerging therapies provide promising opportunities for improving peri-implantitis treatment outcomes; however, current evidence supports their use mainly as adjunctive approaches combined with established mechanical debridement, surgical management, regenerative procedures, and supportive maintenance therapy.

Table 5. Summary of Emerging and Adjunctive Therapies in Peri-implantitis Management

Emerging therapy	Proposed mechanism	Current evidence	Clinical status
Laser-assisted therapy	Antimicrobial effect, bacterial reduction, possible enhancement of tissue healing	Moderate but heterogeneous evidence	Adjunctive therapy [36,39]
Photodynamic therapy (PDT)	Photosensitizer activation and reactive oxygen species-mediated bacterial destruction	Promising short-term microbial reduction	Adjunctive / under investigation [52]
Ozone therapy	Oxidative antimicrobial activity and reduction of pathogenic microorganisms	Limited clinical evidence	Experimental adjunctive approach
Probiotics	Modulation of peri-implant microbiome and reduction of pathogenic bacterial activity	Limited clinical evidence	Experimental
Biomimetic implant coatings	Reduction of bacterial adhesion and improvement of implant–tissue interaction	Early experimental evidence	Investigational [39,40]

3.8 Supportive Maintenance and Prevention of Recurrence

Successful long-term management of peri-implantitis extends beyond active treatment and depends on continuous supportive peri-implant maintenance. Regardless of whether patients receive non-surgical, surgical, or regenerative therapy, long-term disease control requires regular professional monitoring and effective biofilm management to minimize the risk of recurrence. Supportive peri-implant therapy includes professional plaque removal, assessment of probing depth and bleeding on probing, evaluation of peri-implant soft tissue health, reinforcement of patient oral hygiene measures, and radiographic assessment when clinically indicated. Early identification of recurrent inflammation allows timely intervention before additional peri-implant bone destruction occurs [11,42,53].

Current evidence consistently demonstrates that individualized maintenance programs significantly improve long-term implant survival and reduce the incidence of peri-implant disease progression. Patients presenting with a history of periodontitis, smoking, poor plaque control, uncontrolled diabetes, or other systemic risk factors require more frequent follow-up visits and closer clinical monitoring than low-risk individuals [20–22,49]. Recent international consensus recommendations emphasize that prevention should begin before implant placement through careful patient selection, comprehensive risk assessment, appropriate prosthetic planning, and patient education. Following implant restoration, maintenance protocols should include regular professional cleaning every 3–6 months, individualized oral hygiene instruction, control of modifiable risk factors, and early management of peri-implant mucositis to prevent progression to peri-implantitis [42,53–55.] Overall, supportive peri-implant therapy should be regarded as an integral component of contemporary peri-implantitis management rather than a separate phase of treatment. Long-term implant success depends on the combination of effective active therapy, modification of patient-related risk factors, and lifelong maintenance care.

Table 6. Supportive Maintenance Strategies After Peri-implantitis Treatment

Maintenance strategy	Clinical importance
Regular supportive peri-implant therapy	Reduces recurrence and disease progression through continuous biofilm control
Professional plaque removal	Maintains peri-implant tissue health and minimizes bacterial accumulation
Periodic clinical monitoring	Early detection of bleeding on probing, increased probing depth, and recurrent inflammation
Radiographic evaluation when indicated	Monitoring of peri-implant bone stability following treatment

Maintenance strategy	Clinical importance
Control of systemic and behavioral risk factors	Improves long-term treatment predictability and implant survival
Patient education and oral hygiene reinforcement	Enhances plaque control and supports long-term peri-implant health

3.9. Clinical Decision-Making Algorithm for Contemporary Peri-Implantitis Management

Contemporary management of peri-implantitis requires an individualized treatment strategy based on disease severity, defect morphology, implant surface characteristics, patient-related risk factors, and response to initial therapy. Current evidence supports a stepwise treatment concept in which conservative biofilm-control measures are implemented first, followed by surgical and regenerative interventions when clinically indicated. The selection of treatment should also consider implant maintainability, prosthetic design, patient compliance, and long-term prognosis [30–45]. The evidence-based clinical decision pathway used in contemporary peri-implantitis management is summarized in Figure 6, which illustrates the progression from initial non-surgical therapy to advanced surgical and regenerative treatment according to disease severity and clinical response.

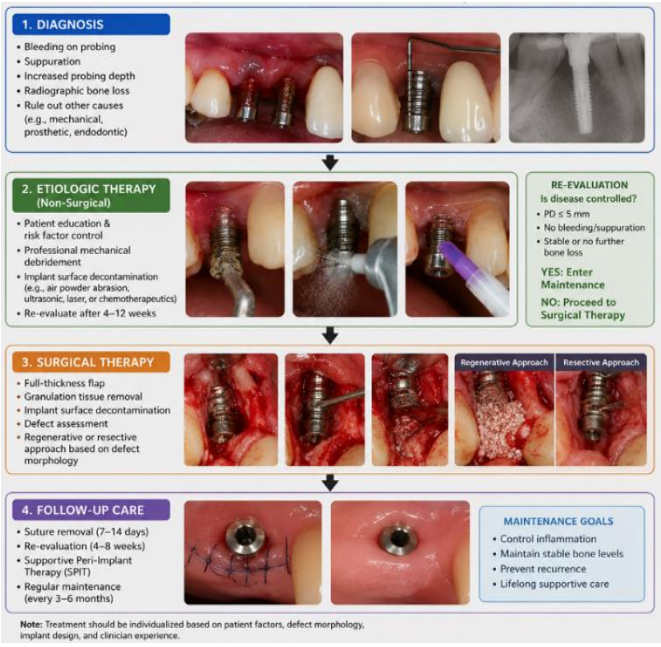

Figure 5. Peri-Implantitis Treatment Algorithm. Clinical decision pathway for peri-implantitis management based on disease severity, peri-implant bone loss, defect morphology, and treatment response.

Table 7. Comparison of Contemporary Treatment Modalities for Peri-implantitis

Treatment modality	Advantages	Limitations	Best clinical indication
Non-surgical therapy	Minimally invasive; effective biofilm reduction	Limited effectiveness in advanced defects	Early peri-implant disease
Surgical therapy	Direct access for implant surface decontamination	More invasive procedure	Moderate peri-implantitis
Regenerative therapy	Potential reconstruction of peri-implant bone defects	Technique-sensitive; depends on defect morphology	Contained intraosseous defects
Emerging adjunctive therapies	May enhance antimicrobial control and tissue healing	Evidence remains limited and heterogeneous	Adjunctive use with conventional therapy

Overall, the treatment algorithm provides a practical framework for evidence-based clinical decision-making while emphasizing individualized therapy according to disease severity, defect characteristics, and patient-specific risk factors. Successful long-term outcomes depend on integrating appropriate active treatment with continuous supportive peri-implant maintenance and regular clinical follow-up [41–45,53–55].

4. DISCUSSION

Peri-implantitis remains one of the most challenging biological complications associated with implant therapy. Although implant survival rates are consistently high, the increasing number of implants placed worldwide has been accompanied by a growing prevalence of peri-implant diseases. Therefore, current research has shifted from simply treating peri-implantitis toward developing predictable strategies that control infection, preserve peri-implant tissues, and maintain implant stability over time [2,3,11,16].

The findings of this systematic review indicate that successful management of peri-implantitis depends on selecting the appropriate treatment strategy according to disease severity rather than applying a universal protocol. Early peri-implant lesions are generally

managed with conservative approaches aimed at biofilm disruption and inflammation control. Mechanical debridement remains the foundation of non-surgical therapy because bacterial biofilm represents the primary factor involved in disease progression. However, complete decontamination of rough implant surfaces remains difficult, supporting the use of additional antimicrobial approaches when clinically indicated [17,30,31,33].

As peri-implantitis progresses and supporting bone loss develops, surgical treatment becomes increasingly important. The reviewed evidence demonstrates that surgical therapy provides improved access to contaminated implant surfaces, facilitates removal of inflammatory tissues, and allows more effective decontamination procedures. The selection of access flap surgery, resective surgery, implantoplasty, or regenerative approaches should be based on defect morphology, implant position, prosthetic accessibility, and long-term prognosis rather than on a standardized approach for all patients [32,34,38,44].

Regenerative treatment represents an important advancement in contemporary peri-implantitis management, particularly for contained intraosseous defects. The application of bone substitute materials, barrier membranes, and biologically active materials may enhance bone reconstruction and improve clinical outcomes when combined with effective infection control and appropriate case selection. Nevertheless, regenerative success remains influenced by defect configuration, implant surface characteristics, and patient compliance with maintenance therapy [34,40,44,50,51].

Adjunctive treatment modalities aimed at improving bacterial control and tissue healing have gained increasing attention. Laser-assisted therapy, photodynamic therapy, ozone therapy, probiotics, and biomimetic implant surface technologies have demonstrated promising results in selected studies. However, the available evidence remains heterogeneous, and these approaches should currently be considered complementary strategies rather than replacements for established mechanical, surgical, and regenerative treatment principles [36,39,40,52]. An important conclusion from the available evidence is that peri-implantitis management does not end after active treatment. Long-term success depends on continuous supportive peri-implant care, including professional maintenance, effective plaque control, reinforcement of oral hygiene measures, and management of patient-related risk factors such as smoking, previous periodontitis, inadequate plaque control, and systemic conditions. These measures play a critical role in reducing recurrence and maintaining implant stability [20–22,35,41–43,53–55].

Limitations of Current Treatment Strategies

Despite significant progress in peri-implantitis treatment, several limitations remain. Current studies demonstrate considerable variability in diagnostic criteria, implant surface decontamination methods, surgical techniques, regenerative materials, maintenance protocols, and outcome assessment. These differences contribute to heterogeneity among studies and limit the establishment of universally accepted treatment recommendations [30–45].

Future Perspectives

The future of peri-implantitis management is expected to be driven by the integration of artificial intelligence, precision diagnostics, and digital technologies into routine clinical practice. Beyond automated image interpretation, AI-based clinical decision-support systems may integrate radiographic findings, patient-related risk factors, microbiological profiles, inflammatory biomarkers, and longitudinal clinical data to facilitate individualized diagnosis, risk stratification, and personalized treatment planning according to disease severity and biological characteristics [56,60].

Future research should prioritize the development of standardized AI validation frameworks based on large multicenter clinical datasets, harmonized imaging protocols, standardized diagnostic criteria, and externally validated machine learning models. In addition, the implementation of explainable artificial intelligence (XAI) algorithms will be essential to improve the transparency, reliability, and clinical acceptance of AI-assisted peri-implantitis management. Prospective randomized clinical trials with long-term follow-up are required to determine whether AI-assisted diagnostic and therapeutic strategies improve implant survival, disease prevention, and patient-reported outcomes compared with conventional approaches [56–61].

Another promising direction involves integrating AI with three-dimensional CBCT analysis, digital implant monitoring systems, salivary and peri-implant crevicular fluid biomarkers, digital twins, and precision medicine concepts. These technologies may enable continuous monitoring of peri-implant tissue health, earlier prediction of disease progression, personalized maintenance protocols, and more timely therapeutic interventions. As these innovations become clinically

validated, they are expected to contribute to more predictable peri-implantitis management and improved long-term implant survival [39–45,53–61].

5. CONCLUSION

This systematic review demonstrates that contemporary peri-implantitis management requires an individualized treatment approach based on disease severity, defect characteristics, implant-related factors, and patient risk indicators. Mechanical biofilm control remains the basis of therapy, while surgical and regenerative approaches provide additional benefits in advanced cases. Emerging adjunctive therapies show potential but require further clinical validation. Long-term supportive maintenance and regular monitoring remain essential for preventing recurrence and preserving implant stability. Further standardized clinical studies are necessary to strengthen the evidence base and improve future treatment strategies for peri-implantitis.

DECLARATIONS

Conflict of Interest

The author declare no conflict of interest.

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Ethical Approval

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