

# Microbial Boundaries in Peri-Implantitis: A Review of Pathogen-Related Advances

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**Received:** 4 September 2024 ♦ **Accepted:** 23 November 2024 ♦ **Published:** 31 December 2024

**Citation:** Talib EQ, Taha GI, Ali DM, Al-Hindawi SH, Al-Khayat F, Hasan IA. Microbial boundaries in peri-implantitis: a review of pathogen-related advances. *Folia Med (Plovdiv)* 2024;66(6):763-769. doi: 10.3897/folmed.66.e136356.

## Abstract

In the field of implantology, peri-implantitis is still a common complication of implant failure. Similar to periodontal disease, this kind of pathological condition is characterized by inflammation of the tissues surrounding dental implants or fillings. The sources of infection have been shown to be chronic periodontitis and poor maintenance of the communion. A thorough examination of the intricate components of peri-implantitis was sought in this review in order to identify common characteristics of the disease with regard to bacteria, biofilm formation, host immunological responses, diagnostic tools, and therapeutic treatments. The aim of this study was to provide a detailed overview of the different bacterial species associated with peri-implantitis, a clinical condition similar to periodontitis, characterized by a higher prevalence of staphylococci and enteric bacteria. The study underscores the importance of employing sophisticated diagnostic methods like cone beam computed tomography. It covers a range of therapeutic approaches including surgical and non-surgical techniques as well as strategies stressing host-modification and photodynamic treatment. The study was conducted using pertinent publications from scientific databases, including Scopus, Google Scholar, PubMed, and Web of Science. We searched these databases using the following terms: periodontitis, microbial, dental implants, peri-implantitis, and biofilm formation.

## Keywords

biofilm formation, implants, microbial, peri-implantitis, periodontitis

## INTRODUCTION

Dentists often worry about peri-implantitis, a disease that causes swelling and pain in the soft and hard tissues around tooth implants.<sup>[1]</sup> The 2017 report from the American Academy of Periodontology says that peri-implantitis is a condition where plaque builds up and causes swelling and a gradual loss of bone support.<sup>[2]</sup> This primarily affects individuals who have previously experienced issues. Frequently, this issue is linked to plaque management. Common symptoms are redness, bleeding during probing, inflammation, and discharge, which resemble

indications of disease, such as sensitive gums surrounding the implants.<sup>[1]</sup>

The prevalence of peri-implantitis differs, with some studies demonstrating that it was 19.53% at the patient-level and 12.53% at the implant-level.<sup>[3]</sup> The disparities in the prevalence of the disease may be explained by differences in the definitions of the illness, the study design, the duration of employment, or the use of probing depth as a diagnostic tool.<sup>[4]</sup> According to the 2017 World Workshop on the Classification of Periodontal and Peri-implant Diseases and Conditions, peri-implantitis may be diagnosed by combining the following criteria: bone loss of the sup-

port  $\geq 3$  mm, periodontal pocket depth (PPD)  $\geq 6$  mm, and bleeding on probing (BOP).<sup>[4,5]</sup>

Peri-implant diseases are broadly divided into two groups: peri-implant mucositis and peri-implantitis. The former is essentially the first stage of peri-implantitis. Mucositis is a lesion where the gingiva around the implant is inflamed, but there is no associated bone loss.<sup>[6]</sup> The redness and swelling of the mucosa are probably the best indicator of the disease, and the tissue may bleed on probing. Apart from restorative phase maintenance path of the inflammation may be reversed.<sup>[1]</sup> On the other hand, peri-implantitis is a later stage of peri-implant disease. It not only affects the gums and causes inflammation, like peri-implant mucositis, but it also spreads to the bone that supports the implant and causes bone loss over time.<sup>[3]</sup> The loss of bone around the tooth implant that cannot be fixed is what makes peri-implantitis different. Some of the signs are sore gums, bleeding, pus coming out of the gums, and the implant slowly coming free because the bone is breaking down. When someone has peri-implantitis, it is harder to treat because they usually need surgery to fix both the soft tissue disease and the bone loss.<sup>[1]</sup>

### Ecological characteristics of the peri-implant niche

A salivary pellicle quickly attaches to oral surfaces after implant insertion. This adsorption mechanism helps first bacterial colonizers connect and serve as surface receptors for later colonizers.<sup>[7]</sup> Edgerton et al.<sup>[8]</sup> showed that titanium and dental enamel pellets formed differently molecularly, titanium pellicles formed in vitro included proteins rich in proline, secretory IgA,  $\alpha$ -amylase, and high molecular weight mucins. These pellicles lacked enamel-like low-molecular-weight mucins and cystatins. Despite these apparent changes, titanium pellicles do not seem to affect bacteria initial adherence.<sup>[9]</sup> Germs colonize the implant site within 30 minutes of implantation. Over the following two weeks, this colonization forms organized biofilm communities in the peri-implant crevice.<sup>[10]</sup> In the initial months following implantation, the peri-implant biofilms have a less diverse microbiome than the surrounding teeth but show little taxonomic changes.<sup>[11]</sup> At this time, the surrounding bacteria may form a mutually beneficial interaction with the host and help sustain implant health. However, several factors that promote biofilm formation also cause tissue inflammation and alter the peri-implant sulcus milieu.<sup>[10]</sup> Dysbiotic microbiota changes due to microenvironment changes exacerbate inflammation and affect peri-implant health and function.<sup>[12]</sup> Schincaglia et al.<sup>[13]</sup> found that *Tannerella*, *Prevotella*, *Fretibacterium*, and *Treponema spp.* increased after three weeks of oral hygiene discontinuation. Locally elevated proinflammatory cytokines were linked to microbial diversity.

### Microbial etiology of peri-implantitis

The inflammatory destruction of implant-supporting tissues caused by biofilm formation on the implant surface is what causes peri-implantitis, a serious dental implant complication.<sup>[14]</sup> This condition is analogous to periodontitis, which affects natural teeth. The microbial composition associated with peri-implantitis is diverse and non-specific but is very similar to that found in periodontitis. A notable exception is the frequent presence of high numbers of staphylococci and enteric bacteria in peri-implantitis cases. Microbiome-based machine learning has shown high diagnostic and prognostic power for peri-implant diseases. In particular, the “peri-implantitis-related complex (PiRC)” is composed of the seven most disease-associated species.<sup>[10,15,16]</sup> This encompasses *Staphylococcus epidermidis*, which can form pathogenic biofilms on implant surfaces; *Fusobacterium nucleatum*, a bridging organism in biofilms; *Treponema denticola*, an invasive pathogen capable of inducing robust immunity and inflammation; *Tannerella forsythia*, which contributes to persistent infection and inflammation; *Prevotella intermedia*, linked to acute and severe clinical conditions; and *Porphyromonas gingivalis*, a significant pathogen that disrupts host immune responses, thereby promoting dysbiosis. These bacteria have been identified and are present in the locations of compromised implants, suggesting a substantial correlation with the pathophysiology of peri-implantitis.<sup>[6,14]</sup> The usual oral microbiota comprises approximately 700 bacterial species, with an average of 296 types per person, despite its association with puffiness, cellular damage, and bone loss.<sup>[10]</sup> Orally transmitted infections have an exceedingly low prevalence in a healthy oral cavity. But when there is a sickness, the number of these microorganisms greatly rises, which throws off the microbiota’s natural balance. This mismatch may also lead to more major problems, like pain and inflammation. If you ignore the damage these germs do, you could end up with long-term problems like losing your teeth and bones.<sup>[16,17]</sup> In peri-implantitis, the microbiome around an implant is messed up because the communities of bacteria are not balanced. This creates a peri-implant sulcus that is always swollen and has pathological proliferators that are not found in healthy teeth. This messed up microbiome makes bone loss worse, which makes it harder for osseointegrated implants to work and look good.<sup>[6,15,18]</sup>

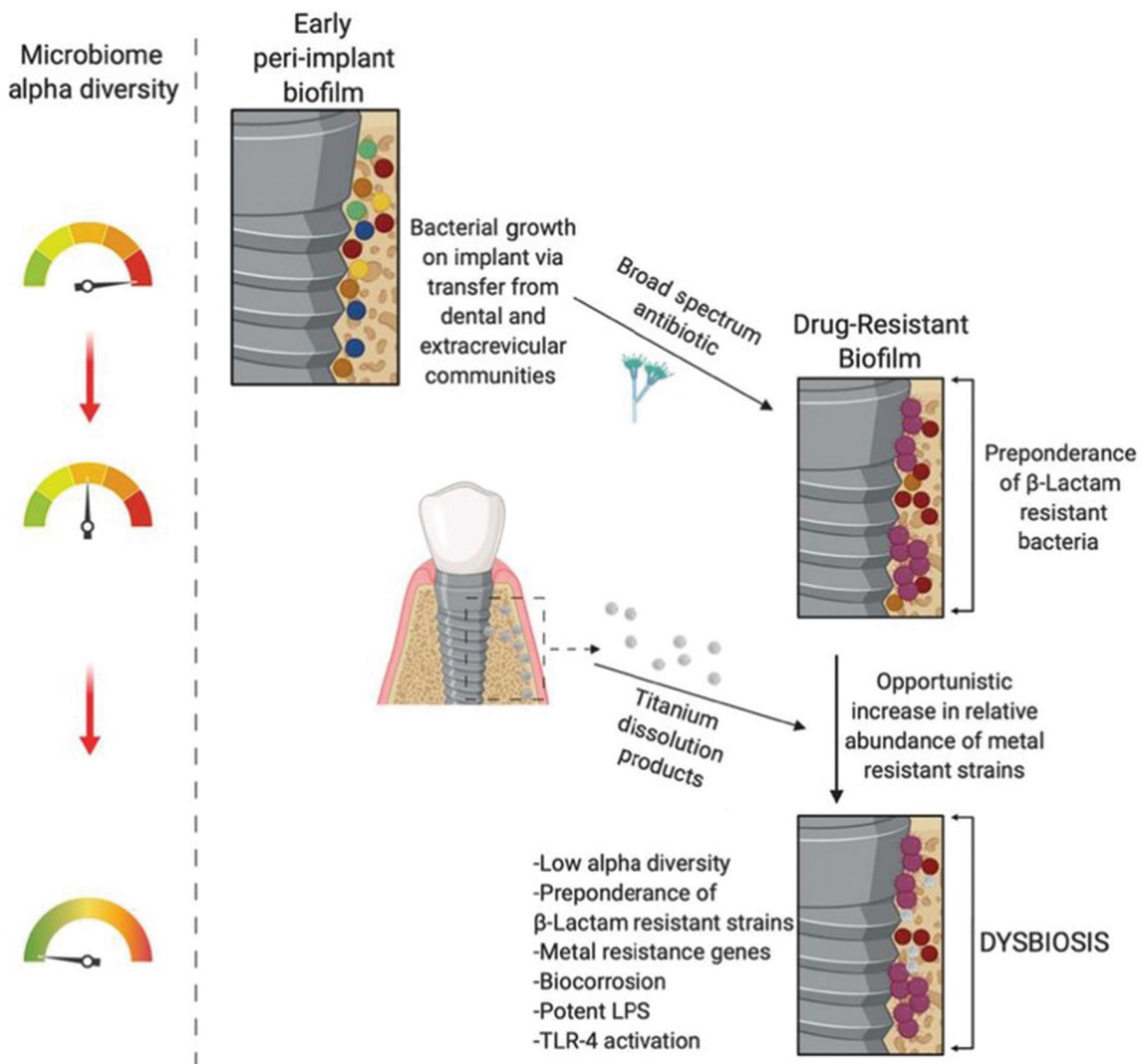
### Biofilm formation and its role

Biofilm formation on dental implants, in which groups of germs form around the implant, is the main cause of peri-implantitis.<sup>[19]</sup> Biofilm formation is attributed to various bacterial species such as *Porphyromonas gingivalis*, *Treponema denticola*, *Tannerella forsythia*, *Aggregatibacter actinomycetemcomitans*, and *Prevotella intermedia*.<sup>[14]</sup> There may be opportunistic bacteria in this biofilm complex, such as *Staphylococcus aureus* and *Pseudomonas aeru-*

*ginosa*, as well as fungi and viruses.<sup>[7]</sup> Bacteria in the tissue around the implant cause swelling, which leads to the loss of bone support. This is a common sign of peri-implantitis.<sup>[20]</sup> There are fewer species of *Porphyromonas* and *Neisseria* in peri-implantitis because the *Firmicutes* group becomes more dominant as biofilm forms.<sup>[10]</sup> The first step is called peri-mucositis, and it involves swelling in the soft tissues around the implant. Peri-implantitis could show up because of this. Bacteria of different types can live between the gums and around the implant. Most of the time, *Fusobacterium* spp. and *Treponema* spp. are found in peri-implantitis, while *Rothia* spp. and *Streptococcus* spp. are found in peri mucositis (Fig. 1).<sup>[10]</sup> This difference suggests that distinct bacterial populations contribute to progression from peri-mucositis to peri-implantitis.<sup>[21,22]</sup>

### Host response and inflammation

The immune system's reaction to germs on the tooth implant is very important for how peri-implantitis progresses and how long it lasts. This happens because biofilm forms on the surface of the implant, which causes inflammation cells to destroy surrounding tissues.<sup>[23,24]</sup> In order to develop peri-implantitis, mouth bacteria and immune cells like macrophages, dendritic cells, mast cells, and neutrophils have to work together in a complicated way.<sup>[25]</sup> Cells produce pro-inflammatory cytokines such as TNF- $\alpha$  and IL-1, initiating an inflammatory cascade in peri-implantitis leading to inflammation and bone deterioration.<sup>[25-27]</sup> Macrophages play two roles in implant function where M1 contributes to dental implant failure by promoting osteol-



**Figure 1.** Local and environmental characteristics contributing to decreased dysbiosis and decreased microbiome alpha diversity in peri-implant disease.<sup>[10]</sup>

ysis and amplifying inflammation, while M2 supports osseointegration and healing. Additionally, peri-implantitis samples show a higher prevalence of M1 macrophages, indicating a significant impact on implant progression.<sup>[10,28]</sup> Peri-implantitis is a disease caused by a dynamic host immune response to microbial colonization, characterized by chemical combinations and immune cells interacting with the bacterial biofilm which leads to tissue damage.<sup>[29,30]</sup>

### Risk factors and predisposing conditions

Peri-implantitis is mostly caused by the immune system's reaction to germs on implants.<sup>[25]</sup> Peri-implantitis is a condition where biofilm builds up and causes inflammation to the tissues that support the implant. This is caused by a complex relationship between the host's immune system and the biofilm.<sup>[26,31]</sup>

It makes the immune system respond like it does to periodontal diseases, letting different types of cells like neutrophils, macrophages, T-cells, and B-cells into the sores.<sup>[32,33]</sup> Peri-implantitis, on the other hand, causes a lot of swelling and the usual immune response. This is not the same as other immunity diseases that hurt tissue.<sup>[31]</sup> Dental implants may damage tissues and make illnesses worse because they are structurally different from normal teeth. They do not have periodontal muscles or Sharpey's fibers, which could make the problem worse.<sup>[34]</sup> Biofilms around devices are made up of different bacteria, some of which are similar to those found in periodontitis but have more goblet cells and staphylococci. The immune system of humans reacts to these bacteria by making cytokines, chemokines, prostaglandins, and protease enzymes that help with inflammation and tissue death.<sup>[30,35]</sup>

### Diagnostic approaches

Peri-implantitis can be diagnosed in several methods, including clinical evaluations, imaging methods and microbial tests.<sup>[35]</sup> Early detection of marginal bone loss is important for planning treatment and figuring out how bad diseases like peri-implantitis are. Traditional two-dimensional (2D) imaging methods, such as intraoral and panoramic radiography, are not as good as cone beam computed tomography (CBCT). Compared to intraoral radiographs, it gives more thorough information about bone defects, especially when it comes to finding vestibular dehiscence and measuring the depth and width of defects.<sup>[36]</sup> Even though CBCT has some benefits, it is not often used in clinical settings because it is expensive and hard to get. It is better than 2D imaging methods, which are less expensive and expose people to less radiation. But 2D images can have problems such as warping, loss of spatial clarity, and enlargement, which could lead to wrong conclusions.<sup>[3,4]</sup> Also, most 2D imaging methods cannot properly spot some situations (this is a problem with all 2D methods), especially in the oral and tongue areas. It is important to think about each patient's unique needs when

coming up with effective testing methods for safely finding and treating peri-implantitis. When picking between periapical radiography, panoramic mouth radiography, and cone beam computed tomography, some of the things that need to be taken into account are the amount of implants, the type of implants used, and health problems like diabetes or osteoporosis.<sup>[10,31,34]</sup> Like in periodontitis, the germs in peri-implantitis biofilms are not specialized and are very different from one another. When someone has peri-implantitis, they often have *Staphylococci* and gut germs.<sup>[37]</sup> By looking at illnesses and the immune system's reaction to them, this comparison is key to understanding what causes peri-implant diseases.<sup>[26,37]</sup> Microbiology tests are very important for finding and stopping peri-implantitis early on because they help us understand how it works at the molecular level. Collecting and analyzing peri-implant crevicular fluid without hurting the patient can show how quickly the situation is getting worse. This could be because of more inflammation and a natural immune reaction, which causes serious tissue damage and faster progression. Differences in the structure between normal teeth and implants may also play a role.<sup>[25,26,37]</sup>

### Therapeutic strategies and management

New developments in photodynamic therapy and host-modulating drugs have changed the way peri-implantitis is treated, mixing non-surgical and surgery methods.<sup>[32]</sup> For better long-term results, surgery like augmentative therapy is often needed for severe peri-implantitis. However, mechanical and antibiotic treatments work better in the early stages.<sup>[38]</sup> When choosing patients for advanced treatments, it is important to think about things like their overall health, the type of surgery they need, and their personal tastes. Problems with implementation include the need for technical know-how and patient teamwork. Even though they cost more at first, modern methods can save money in the long run because they work better and less often.<sup>[37]</sup>

For diabetic patients with multiple implants, doctors may use CBCT imaging and antimicrobial treatment. For more complicated cases, like serious peri-implantitis with significant bone loss<sup>[4]</sup>, augmentative treatment and graft placement are better. Case studies on photodynamic treatment (PDT) could show its benefits and usefulness in real life, which could lead to more doctors using it.<sup>[15]</sup>

### Non-surgical treatment

- **Mechanical therapy:** The effectiveness of mechanical non-surgical methods like root planing and scaling in treating peri-implant mucosal lesions has been demonstrated.<sup>[32]</sup>
- **Antimicrobial mouth rinses:** Using antimicrobial mouth rinses, such as chlorhexidine, enhances the effectiveness of mechanical treatments for mucosal lesions.<sup>[32,38]</sup>

- **Antibiotics:** The use of local or systemic antibiotics can reduce bleeding on probing and probing depths in peri-implantitis lesions.
- **Laser therapy:** Laser therapy has shown minor beneficial effects on peri-implantitis, although its efficacy requires further evaluation.<sup>[38]</sup>

## Surgical treatment

- **Open flap debridement (OFD):** This method involves exposing the implant surface for direct debridement, thereby mitigating inflammation around the implant.<sup>[32,38]</sup>
- **Respectful therapy (RT):** Indicated for supracrestal bone defects, RT involves the reduction or removal of pathological peri-implant pockets, with procedures like implantoplasty.<sup>[38]</sup>
- **Augmentative therapy (AT):** Known as regenerative treatment, AT involves flap elevation, mechanical debridement, and placement of graft material, aiming to regenerate bone defects and achieve re-osseointegration. AT has been shown to be superior to OFD in improving the peri-implantitis outcomes.<sup>[39]</sup>
- **Combination therapies:** These surgical treatments are often combined with adjuvant therapies like laser therapy, photodynamic therapy, and local antibiotics.<sup>[39]</sup>

## Recent advancements and potential future therapies

- **Photodynamic therapy and pharmacological agents:** These have emerged as successful treatment options, focusing on the reduction of microbial load and eradication of pathogenic bacteria.<sup>[39]</sup>
- **Host modulating therapies:** These novel therapeutics, which act on the host immune mechanism, have shown effectiveness in treating peri-implant diseases.<sup>[32]</sup>
- **Advanced surgical modalities:** The use of guided bone regeneration, artificial intelligence, micro CT, and computer-assisted diagnosis and surgery represent the latest advancements in surgical treatment options for peri-implantitis.<sup>[39]</sup>

## Role of antibiotics and antimicrobial therapy

The management of peri-implantitis involves the strategic use of antibiotics and antimicrobial agents, both systemically and locally.<sup>[1]</sup>

### Systemic antibiotics

Systemic antibiotics have not consistently been shown to improve clinical outcomes in the surgical treatment of peri-implantitis. Most systematic reviews and studies show little to no significant long-term benefit from the adjunctive use of systemic antibiotics. However, some evidence suggests a temporary advantage in certain situations, such as cases involving modified surface implants.<sup>[37,40]</sup>

For decades, the use of systemic antibiotics before surgery in peri-implantitis sites (e.g., brushes, insertion devices, lifting devices) has been a contentious issue. While existing implant placement protocols recommend antibacterial prophylactic measures, further studies have shown that such treatment does not enhance implant survival in straightforward surgeries involving healthy individuals. The lack of high-quality data from randomized controlled trials (RCTs) and the wide variability in diagnostic criteria contribute to the ongoing debate regarding the effectiveness and necessity of systemic antibiotics in the treatment of peri-implantitis.<sup>[40,41]</sup> Although systemic antibiotics are generally contraindicated for peri-implantitis, amoxicillin and metronidazole are often used due to their broad-spectrum efficacy against aerobic and anaerobic bacteria, respectively. Clindamycin is an alternative for individuals allergic to penicillin, while azithromycin offers the added benefits of biofilm penetration and inflammation reduction. Doxycycline serves as both an antibacterial agent and a matrix metalloproteinase inhibitor, helping to prevent tissue damage.<sup>[40,41]</sup>

Local antibiotics

### Local antibiotics

The use of locally administered antibiotics significantly reduces peri-implantitis indicators like peri-implant probing depth and bleeding on probing compared to control groups.<sup>[5]</sup> Several studies show that applying antibiotics locally lowers probing pocket depth and bleeding much more than applying them non-locally. This shows that it works and does not have any bad effects.<sup>[40]</sup>

Along with mechanical cleaning and chemical washing, local antibiotics like minocycline nanoparticles and doxycycline gel are used to get the drugs to the spot where they are needed. Antibiotics are delivered to gaps around implants by tetracycline fibers, metronidazole gel fights anaerobic infections, and chlorhexidine chips kill germs. Even though they do not have big effects, local medicines can help treatment work better.<sup>[41]</sup>

## CONCLUSION

Peri-implantitis progression is influenced by the host immune system, biofilm and bacterial presence. In order to treat this oral condition, early detection, preventative measures, and advanced therapies are essential. Advanced surgical techniques and host-modulating therapies show promise for treatment results.

## Author contributions

All authors have read and approved of the final manuscript.

## Conflict of Interest

The authors declare that they hold no competing interests.

## Funding

The authors have no funding to report.

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## Микробные границы при периимплантите: обзор достижений в области патогенных исследований

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**Дата получения:** 4 сентября 2024 г. ♦ **Дата приемки:** 23 ноября 2024 г. ♦ **Дата публикации:** 31 декабря 2024 г

**Образец цитирования:** Talib EQ, Taha GI, Ali DM, Al-Hindawi SH, Al-Khayat F, Hasan IA. Microbial boundaries in peri-implantitis: a review of pathogen-related advances. *Folia Med (Plovdiv)* 2024;66(6):763-769. doi: 10.3897/folmed.66.e136356.

### Резюме

В области имплантологии периимплантит по-прежнему является распространённым осложнением неудач имплантации. Подобно пародонтозу, этот вид патологического состояния характеризуется воспалением тканей, окружающих зубные имплантаты или пломбы. Было показано, что источниками инфекции являются хронический пародонтит и плохой уход за дёснами. В этом обзоре было предпринято тщательное изучение сложных компонентов периимплантита с целью выявления общих характеристик заболевания в отношении бактерий, образования биоплёнки, иммунологических реакций реципиента, диагностических инструментов и терапевтических методов лечения. Целью этого исследования было предоставить подробный обзор различных видов бактерий, связанных с периимплантитом, клиническим состоянием, похожим на пародонтит, характеризующимся более высокой распространённостью стафилококков и кишечных бактерий. Исследование подчёркивает важность использования сложных диагностических методов, таких как конусно-лучевая компьютерная томография. Оно охватывает ряд терапевтических подходов, включая хирургические и нехирургические методы, а также стратегии, подчеркивающие модификацию реципиента и фотодинамическое лечение. Исследование проводилось с использованием соответствующих публикаций из научных баз данных, включая Scopus, Google Scholar, PubMed и Web of Science. Мы осуществили поиск в этих базах данных, используя следующие термины: пародонтит, микробный, дентальные имплантаты, периимплантит и образование биоплёнки.

### Ключевые слова

образование биоплёнки, имплантаты, микробный, периимплантит, пародонтит