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Keywords: Dental implants; Peri-implantitis; Osseointegration; 3D navigation; Nanotechnology

Short Communication

Innovative Strategies in the Prevention and Treatment of Peri-implantitis

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Abstract

Background: The field of dental implantology has recently experienced significant progress, transforming the approach to replacing lost teeth. Dental implants provide a reliable and long-lasting option for individuals seeking to regain their oral functionality and enhance their visual appeal. Nevertheless, obtaining successful results in dental implant procedures necessitates a thorough comprehension of the different factors that affect the success of the implants.

Objective: This manuscript aims to summarize current clinical insights and technological advancements in preventing and managing peri-implantitis. The paper highlights the importance of minimally invasive techniques, combined with augmentation procedures, in the gap between the implant and the alveolar walls, as this can lead to osseointegration and long-term stability of peri-implant hard and soft tissues. Additionally, it highlights the integration of digital tools such as 3D navigation and AI-assisted planning for accurate implant positioning and prosthetic design. This includes employing advanced materials, such as nano-coated implants and nanoparticles incorporated into artificial bone, as it boosts osseointegration and minimizes the likelihood of infection and inflammatory reactions.

Conclusion: Achieving a holistic understanding of thorough diagnostic assessments, modern surgical techniques, and advanced digital workflows is essential for successful implant therapy and the prevention of peri-implantitis. Further research and clinical application of nanotechnology promise to improve implant stability and longevity. Such an approach will enhance patient outcomes and quality of life.

Introduction

It is estimated that around 12-18 million implants are sold annually globally. There is a high likelihood that a patient visiting a dental practice will have at least one dental implant in situ is high [1]. This reinforces the need for general dentists to acquire the knowledge and skills to diagnose and appropriately manage disease around implants.

Peri-implantitis is characterized by a destructive inflammatory lesion of polymicrobial etiology that affects both soft and hard tissues, leading to progressive peri-implant bone loss and the formation of a pocket and inflammation in peri-implant tissues. Modern dentistry is undergoing rapid changes due to the introduction of innovative technologies, particularly in implantology. This has underscored the need for a comprehensive approach to preventing and treating periodontal diseases, particularly with the use of new materials that promote implant osseointegration [2,3].

Etiology and clinical features of peri-implantitis

Peri-implantitis is an inflammatory disease that develops due to infection of the tissues around the implant. The main factors (Figure 1) contributing to its occurrence are:

Clinical manifestations of peri-implantitis include swelling, redness, bleeding gums, pain when touched and during chewing, and gradual bone loss. These symptoms can range from mild, indicating an early stage of the disease, to severe, where bone loss becomes critical to implant stability [4].

Classification of periodontal and peri-implant diseases

For a comprehensive approach to diagnosing and treating

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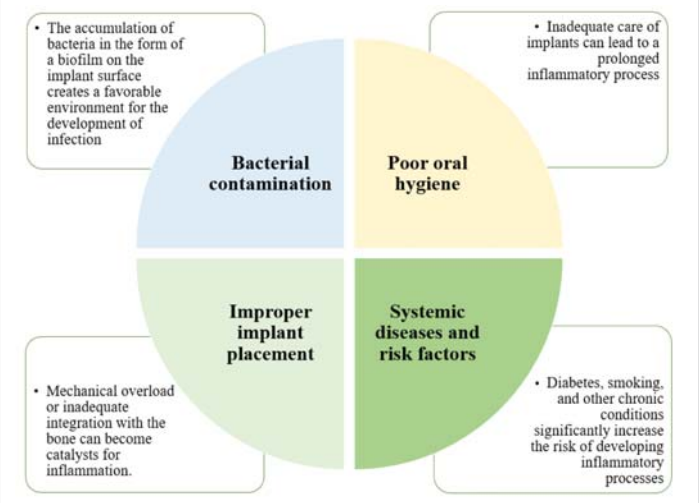

Figure 1: Main reasons for peri-implantitis. (Adapted from existing literature and created by the authors).

peri-implant diseases and conditions, it is essential to have a clear understanding of their classification [5]. *According to the American Dental Association (ADA) and the International Classification of Diseases, 10th Revision, Clinical Modification (ICD-10-CM), peri-implant diseases are categorized under diagnostic codes K08.81 (Peri-implantitis) and K08.89 (Other specified disorders of teeth and supporting structures), supporting accurate clinical documentation and classification* [6,7].

According to 'The 2017 World Workshop', peri-implant diseases, in general, can be divided into four major categories (Figure 2) [8].

Peri-implant mucositis is characterized by clinical signs of inflammation around the soft tissues surrounding a dental implant without signs of progressive marginal bone loss of more than 2 mm after supra-structure installation [8.].

Peri-implantitis is characterized by inflammation around the peri-implant tissues, typically with deepening of probing pocket depths concomitantly with progressive supporting bone loss (more than 2 mm) beyond the initial bone remodeling phase after prosthesis installation. Without previous clinical and/or radiographic records, peri-implantitis can be defined as the combination of ≥ 3 mm bone loss from the crestal bone level and ≥6 mm probing depths with bleeding or suppuration [8].

As mentioned above, peri-implantitis is a considerable biological complication with unpredictable progression rates. Therefore, prevention is key to reducing the risk of peri-implant diseases. Recently, an Implant Disease Risk Assessment (IDRA) tool [9] was developed by Heitz-Mayfield and co-workers to determine a patient's risk profile in developing peri-implant diseases [9]. Eight parameters are proposed, each with criteria categorizing low, medium, or high

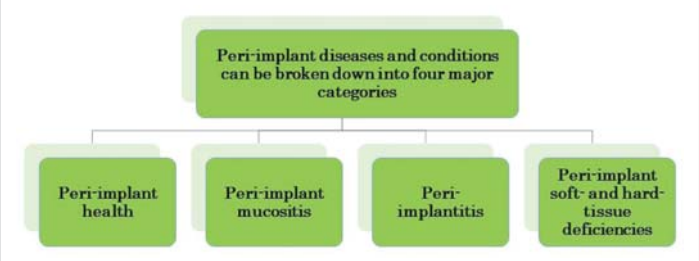

Figure 2: Categories of peri-implant diseases and conditions. (Adapted from existing literature and created by the authors).

risk. As a result, the tool determines the patient's overall risk profile. Generally, a high-risk patient is categorized as having at least two parameters in the high-risk category. A low-risk patient has all parameters in the low-risk category, or at most, one parameter is categorized as moderate risk [9]. The tool helps guide clinicians on the need to modify higher-risk parameters. It is important to note that one non-modifiable parameter is a history of periodontitis. Therefore, identifying this cohort of patients with implants is crucial, as the criteria to be labeled low-risk are more stringent.

With the ever-increasing demand for implant placement to restore edentulous sites, the prevalence of peri-implant diseases is expected to increase. The first step in appropriately managing such diseases is correctly diagnosing peri-implant health, peri-implant mucositis, or peri-implantitis [10]. This is particularly important for patients with a history of periodontitis with a higher risk of peri-implant disease [3,4]. As a result, prevention of peri-implant diseases is imperative, particularly for high-risk patients.

Diagnosis is attained through probing, appreciation of clinical signs such as bleeding and/or suppuration, and radiographic assessment. Additionally, using the IDRA tool will guide clinicians in highlighting higher-risk patients requiring more stringent and closer follow-up.

Clinician's expertise in implant success and peri-implantitis prevention

A clinician's expertise is pivotal for the success of dental implants and the prevention of peri-implantitis. The success of implant therapy goes further than just choosing high-quality materials; it requires meticulous planning, precise surgical techniques, and navigating complex anatomical structures using advanced tools such as 3D imaging and computer-assisted navigation [11].

Clinicians play a crucial role in ensuring implant success and preventing peri-implantitis by integrating several key aspects into their practice. Comprehensive treatment planning is essential, beginning with a thorough assessment of the patient's medical history and risk factors. Advanced imaging techniques, such as CBCT scans [12], allow for precise evaluation of bone quality and quantity [12,13]. Adopting a

prosthetically driven approach [14], clinicians can optimize both function and esthetics when determining implant positioning [14].

Surgical management insight

Surgical expertise is equally important in achieving long-term success. Atraumatic extraction techniques and ridge preservation help maintain bone volume, while careful flap design and suturing promote optimal soft tissue healing [15]. Minimally invasive techniques reduce postoperative complications and enhance recovery and overall outcomes [15].

Integrating 3D navigation [16] and digital workflows has revolutionized implantology [16]. Computer-guided surgery allows for more precise implant placement and reduces surgical risks [17], while digital impressions ensure accurate prosthetic design [17]. AI-assisted planning [18,19] adds another layer of predictability and safety, improving overall treatment success [18,19].

Managing peri-implant soft tissues and occlusion is critical to reducing the risk of complications. Proper contouring of the surrounding tissues helps minimize plaque accumulation, while careful occlusal adjustments prevent excessive forces on the implant. Selecting biocompatible materials further promotes tissue health [20] by minimizing inflammatory responses [20]. Precise surgical placement of dental implants is vital for osseointegration, the process through which the implant fuses with the surrounding bone.

Long-term maintenance and patient education are fundamental to implant longevity. Establishing personalized hygiene protocols ensures patients can effectively care for their implants [21]. Regular follow-ups, including radiographic and clinical assessments, help detect potential issues early. Additionally, timely intervention in cases of peri-implant mucositis can prevent progression to more severe complications [22] (Figure 3).

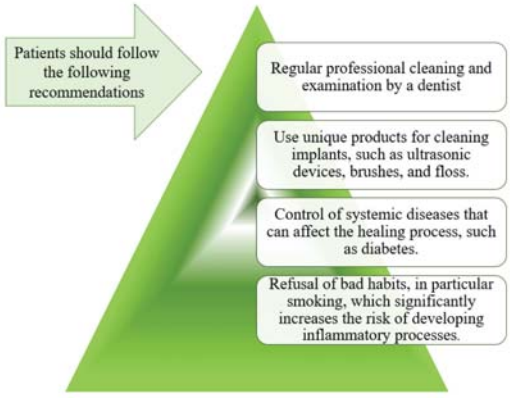

Figure 3: The basis of prevention of peri-implantitis. (Adapted from existing literature and created by the authors).

By combining these principles, clinicians can significantly enhance the success of dental implants while reducing the risk of peri-implantitis, ultimately improving patient outcomes and quality of life [23].

The latest technologies in implantology

The modern development of nanotechnology allows the creation of materials that significantly increase the effectiveness of implantation and reduce the risk of peri-implantitis. The following innovative approaches are particularly noteworthy:

Implants with nano coating

The use of titanium implants with hydroxyapatite nanoparticles promotes better osseointegration. Nanocoating creates an optimal surface for bone cell adhesion, which provides a stronger connection between the implant and the bone. In addition, some nanocoatings have antimicrobial properties, which reduce the risk of bacterial contamination.

Nanoparticle coatings and nano-structuring advancements enhance implant osteointegration and functionality [24]. These nanotech applications can create organized (isotropic) or disorganized (anisotropic) surface patterns, with dental implants often using anisotropic templates because of structural complexity. Titanium dioxide nanoparticles, for instance, have recently been explored for their antimicrobial properties [25].

Various methods create nano-features on implant surfaces, classified as chemical (e.g., anodic oxidation, acid/oxidant treatments) or physical (e.g., plasma spray, blasting) [26]. Additionally, antimicrobial peptides like LL37 (a cationic antimicrobial peptide derived from human cathelicidin, primarily involved in host defense mechanisms by disrupting microbial membranes, modulating immune responses, and promoting wound healing) can be immobilized on implant surfaces to provide antimicrobial and angiogenic effects [27]. Both soluble and immobilized LL37 peptides are effective against Gram-positive and Gram-negative bacteria in 10% human serum, with the immobilized form showing lower cytotoxicity to endothelial cells.

Artificial bone materials incorporating nanoparticles

Innovative materials that mimic natural bone tissue stimulate cell growth and the formation of new bone around the implant. Nanoparticles included in the composition of artificial bone help reduce the risk of implant rejection, promoting faster healing and integration. This is especially important for patients with bone deficiency or insufficient natural bone for stable implantation.

Nanophase materials offer promising solutions for treating bone deformities and defects. Two leading materials

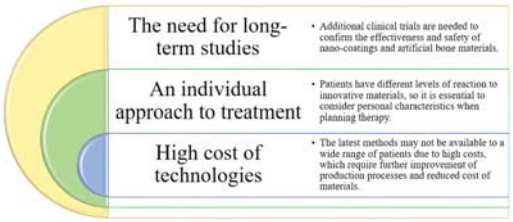

Figure 4: Challenges and limitations of nanotechnology in dentistry. (Adapted from existing literature and created by the authors).

are nanophase hydroxyapatite and carbon. Nanophase hydroxyapatite promotes superior osteoblastic adhesion and is used in products such as NanOSSTM HA, Vitosso HA + tricalcium phosphate, and Ostim HA [28]. In contrast, carbon nanophase combines nanoscale properties with characteristics similar to natural hydroxyapatite, making it a strong candidate for future maxillofacial defect correction and implant applications [29].

Prospects and challenges

Using nanotechnology in implantology opens up new horizons for improving treatment outcomes. However, despite the numerous advantages, the implementation of these technologies is accompanied by specific challenges (Figure 4):

Conclusion

Modern strategies for the prevention and management of peri-implantitis, such as using implants with nanocoating and artificial bone incorporating nanoparticles, represent promising directions in modern dentistry. Careful understanding of the classification of periodontal diseases, to which peri-implantitis belongs, allows us to understand the pathogenesis of the disease better and develop effective methods of prevention and treatment. Further research and clinical trials of the latest technologies will help reduce the risk of implant rejection and improve patients' quality of life. Emerging strategies in treatment and material optimization offer new opportunities for instant diagnostic feedback, improved efficacy, and reduced side effects, which can significantly enhance patient rehabilitation.

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Author contributions

ML: Conceptualization, Investigation, Writing-original draft, Writing-review & editing, Supervision.

NT: Conceptualization, Investigation, Validation, Writing-original draft, Writing-review & editing.

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