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Titanium innovations: Transforming dentistry with advanced materials: A narrative review

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Abstract

Titanium has emerged as a fundamental material in various aspects of dentistry due to its exceptional properties, including biocompatibility, strength, and corrosion resistance. This abstract provides an overview of the application of titanium in dentistry, focusing on its role in dental implants, orthodontic appliances, prosthetic components, and other clinical applications. Titanium dental implants have revolutionized tooth replacement by offering stable and durable solutions that promote osseointegration and preserve bone health. In orthodontics, titanium alloys are utilized for brackets, wires, and other appliances, providing strength and flexibility for efficient tooth movement. Additionally, titanium-based prosthetic components, such as crowns and bridges, offer reliable restorative options with lifelike aesthetics and long-term durability. The versatility of titanium continues to drive advancements in dental materials and technologies, with ongoing research efforts focused on enhancing surface properties, exploring novel alloys, and integrating digital workflows. As titanium remains at the forefront of dental materials science, its widespread application underscores its significance in improving patient outcomes and advancing oral healthcare.

Keywords: Titanium; Dental Implants; Orthodontic Appliances; Prosthetic Components

1. Introduction

Titanium and its alloys have become indispensable materials in modern dentistry due to their excellent biocompatibility, corrosion resistance, and mechanical properties. This review explores the various applications of titanium in dental practice, including dental implants, orthodontic appliances, and prosthetic components.[1]

Dental Implants: Titanium dental implants have revolutionized the field of restorative dentistry by providing a reliable solution for replacing missing teeth. The biocompatibility of titanium allows for osseointegration, the process by which the implant fuses with the surrounding bone tissue, ensuring stability and longevity. Titanium implants offer several advantages, including high strength, low density, and resistance to corrosion, making them suitable for long-term use in the oral environment. Furthermore, the versatility of titanium allows for the fabrication of implants with different designs and surface modifications to enhance osseointegration and soft tissue response.[2]

Properties of Titanium for Dental Implants: Titanium exhibits exceptional biocompatibility, allowing for successful osseointegration, the process by which the implant fuses with the surrounding bone tissue. This biocompatibility minimizes the risk of adverse reactions and ensures long-term stability of the implant. Additionally, titanium's high strength-to-weight ratio and corrosion resistance are crucial for withstanding the mechanical forces and harsh oral environment encountered in the mouth.

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Manufacturing Processes: The manufacturing of titanium dental implants involves several key processes to achieve precise dimensions, surface characteristics, and biocompatibility. The most common method is precision machining, where titanium rods are machined into the desired implant shape. Surface modifications, such as sandblasting, acid etching, or plasma spraying, are often employed to enhance osseointegration by creating a roughened surface that promotes bone attachment [3,4]

Clinical Applications: Titanium dental implants are used to replace missing teeth and restore oral function and aesthetics. They are typically composed of three parts: the implant fixture, abutment, and prosthetic crown. The implant fixture is surgically placed into the jawbone, where it serves as an artificial tooth root. The abutment connects the implant fixture to the prosthetic crown, which mimics the appearance and function of a natural tooth. Titanium implants can support single-tooth restorations, implant-supported bridges, and even full-arch prostheses, providing patients with durable and lifelike tooth replacements.

Advantages of Titanium Dental Implants: Titanium dental implants offer several advantages over traditional tooth replacement options, such as removable dentures or fixed bridges. They provide superior stability and functionality, allowing patients to eat, speak, and smile with confidence. Furthermore, titanium implants preserve bone health by stimulating natural bone remodeling through the process of osseointegration. Unlike removable dentures, which can cause discomfort and require frequent adjustments, titanium implants offer a permanent and reliable solution for tooth loss.[5]

Orthodontic Appliances: Titanium alloys are widely used in orthodontics for the fabrication of brackets, wires, and other components due to their favorable mechanical properties and biocompatibility. Titanium brackets offer superior strength and durability compared to traditional stainless steel brackets, allowing for smaller and more aesthetically pleasing designs. Additionally, titanium wires exhibit greater flexibility and resilience, providing efficient tooth movement while minimizing discomfort for the patient. The biocompatibility of titanium alloys reduces the risk of allergic reactions and soft tissue irritation commonly associated with other materials used in orthodontic appliances.

Prosthetic Components: Titanium is also employed in the fabrication of various prosthetic components, including crowns, bridges, and denture frameworks. Titanium's biocompatibility ensures compatibility with oral tissues, minimizing the risk of adverse reactions and promoting tissue health. Additionally, the lightweight nature of titanium makes it an ideal choice for prosthetic frameworks, providing comfort and stability for the patient. Titanium-based alloys offer excellent mechanical properties, allowing for the fabrication of thin and durable prosthetic components with minimal bulkiness.[6,7]

2. Latest Advances of Titanium in Dentistry [8,9,10]

Titanium continues to evolve as a cornerstone material in dentistry, with ongoing research and development efforts aimed at improving its properties and expanding its applications. In recent years, several advances have been made in the use of titanium in various aspects of dental practice. This review highlights some of the latest advances and innovations in titanium-based dental materials and technologies.

1. Nanostructured Titanium Surfaces: One of the latest advancements in titanium dental implants involves the use of nanostructured surfaces to enhance osseointegration. Figure 1 Nanostructured titanium surfaces exhibit increased surface roughness at the nanoscale, which has been shown to promote faster bone healing and stronger bone-implant integration compared to conventional microstructured surfaces.[9] These nanostructured surfaces can be achieved through various techniques, including anodization, acid etching, and plasma spraying, offering promising improvements in implant success rates and clinical outcomes.
2. Additive Manufacturing (3D Printing) of Titanium Implants: Additive manufacturing, also known as 3D printing, has emerged as a transformative technology in dentistry, allowing for the fabrication of custom-designed titanium implants with intricate geometries and patient-specific features. This technology enables dentists and prosthodontists to design and manufacture implants that precisely fit each patient's unique oral anatomy, improving the accuracy and predictability of implant placement. Additionally, additive manufacturing offers the potential for rapid production and cost-effective customization of titanium implants, paving the way for personalized treatment solutions in implant dentistry.
3. Titanium-Based Alloys with Enhanced Properties: Recent advancements in materials science have led to the development of titanium-based alloys with enhanced mechanical properties and biocompatibility for dental applications. These alloys may include additions of elements such as zirconium, niobium, or tantalum, which can further improve the strength, corrosion resistance, and biological response of titanium implants. By

tailoring the composition and microstructure of titanium alloys, researchers aim to optimize implant performance and longevity while minimizing the risk of adverse reactions and implant failure.

4. Surface Coatings and Modifications: Researchers are exploring innovative surface coatings and modifications to improve the biological and mechanical properties of titanium dental implants. These coatings may include bioactive ceramics, growth factors, or antimicrobial agents, which can enhance osseointegration, reduce bacterial colonization, and mitigate peri-implant inflammation. Additionally, surface modifications such as laser ablation, plasma treatment, or ion implantation are being investigated to create controlled surface topographies and chemistries that promote favorable tissue responses and implant stability.

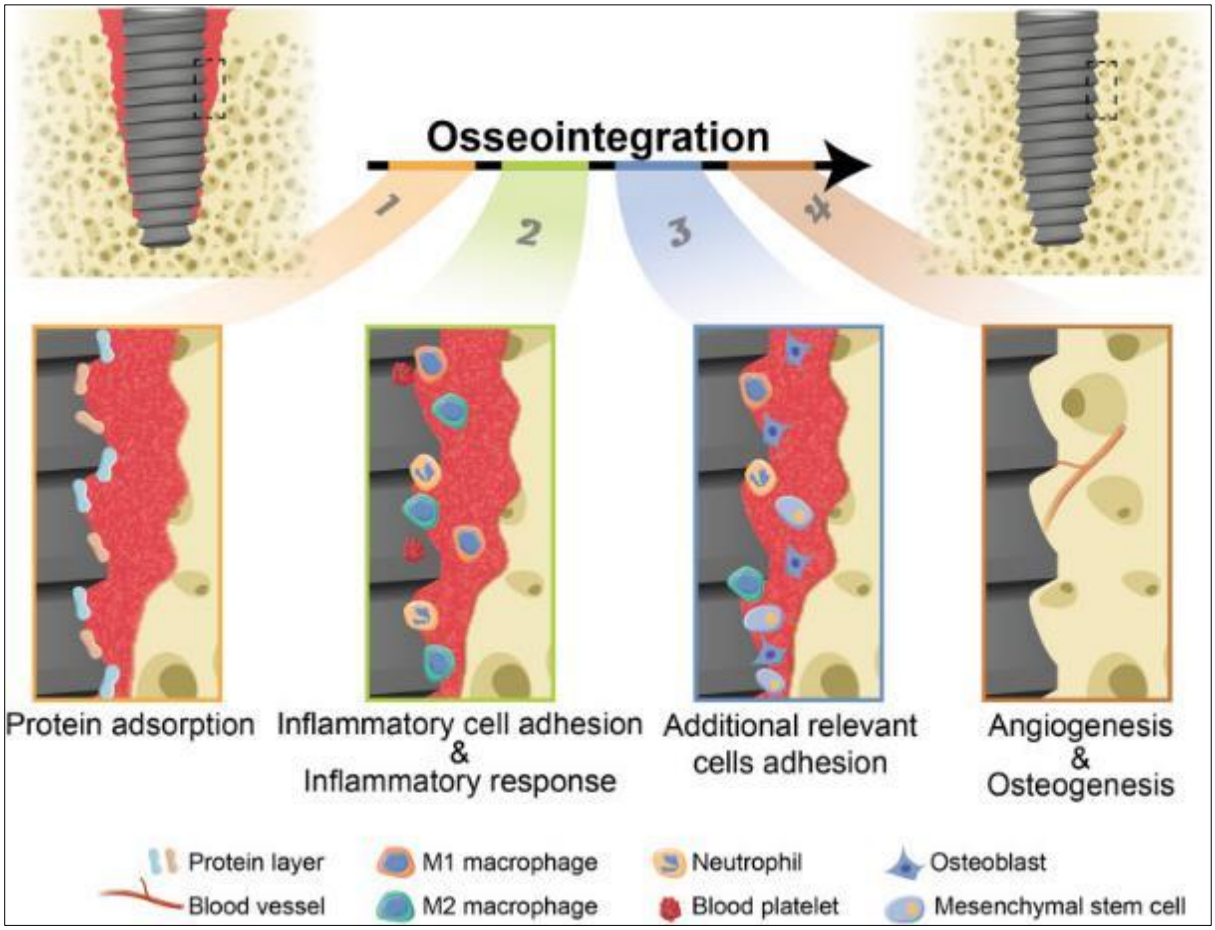

Figure 1 Schematic illustration of the implant-bone osseointegration process. According to different pivotal biological processes, we define osseointegration into four stages: protein adsorption, inflammatory cell adhesion/inflammatory response, additional relevant cells adhesion, and angiogenesis/osteogenesis. The biological process in each stage has close relation with the titanium implant surface. It should be noted that although the stage "angiogenesis" is categorized as the last stage, it indeed runs through the entire osseointegration process[9]

Nanostructuring: Nanostructuring involves creating surface features at the nanometer scale, typically through processes such as acid etching, anodization, or laser ablation. Nanostructured titanium surfaces exhibit increased surface roughness and specific surface area, which can promote protein adsorption, cell attachment, and osteogenic differentiation, leading to accelerated osseointegration. Nanostructured surfaces have shown promise in preclinical studies for enhancing bone healing and implant stability.[11,12,13] Nano-octahedron CeO2 coating on titanium would have great therapeutic potential for alleviating and eliminating peri-implantitis[13] figure 2.

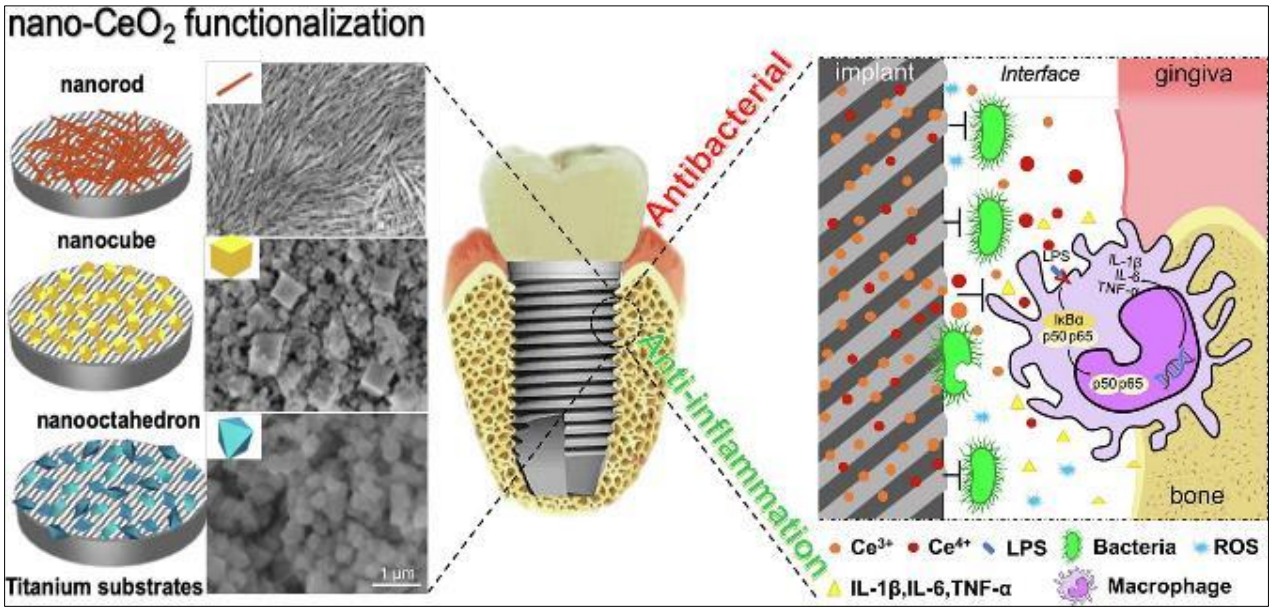

Figure 2 Nano-octahedron CeO_2 coating on titanium[13]

Bioactive Coatings: Bioactive coatings are applied to titanium implant surfaces to impart bioactivity and enhance tissue integration. These coatings may contain bioactive ceramics, such as hydroxyapatite (HA) or calcium phosphate (CaP), which mimic the composition of natural bone and stimulate bone formation. Bioactive coatings promote osteoconduction and osteointegration, facilitating the bonding between implant and bone tissue and improving the long-term success of dental implants.

Antimicrobial Coatings: Antimicrobial coatings are designed to reduce bacterial adhesion and biofilm formation on titanium implant surfaces, thereby minimizing the risk of peri-implant infections and implant failure. These coatings may incorporate antimicrobial agents, such as silver nanoparticles, chlorhexidine, or antibiotics, which exhibit broad-spectrum antimicrobial activity against pathogenic bacteria commonly found in the oral cavity. Antimicrobial coatings help maintain peri-implant tissue health and prevent complications associated with implant placement.[14]

Surface Functionalization: Surface functionalization involves modifying the chemical composition of titanium implant surfaces to introduce specific functional groups or ligands that can interact with biological molecules or cells. Functionalization techniques, such as plasma treatment or chemical grafting, enable the attachment of bioactive molecules, growth factors, or cell-adhesive peptides to the implant surface, promoting cell adhesion, proliferation, and differentiation. Surface functionalization enhances the biological response of titanium implants and facilitates tissue integration and regeneration.[15]

Surface Texturing: Surface texturing techniques, such as sandblasting, acid etching, or microarc oxidation, are used to create microscale features and roughness patterns on titanium implant surfaces. Textured surfaces enhance mechanical interlocking between implant and bone tissue, improving initial stability and facilitating osseointegration. Additionally, surface texturing promotes the formation of a peri-implant soft tissue seal, reducing the risk of bacterial infiltration and peri-implant inflammation.[16]

Multifunctional Coatings: Multifunctional coatings combine multiple functionalities, such as bioactivity, antimicrobial properties, and drug delivery capabilities, into a single coating layer applied to titanium implant surfaces. These coatings offer comprehensive solutions for enhancing tissue integration, preventing infections, and promoting tissue regeneration. Multifunctional coatings may incorporate nanomaterials, smart polymers, or bioactive agents, providing tailored solutions for specific clinical applications and patient needs.[17]

5. Digital Workflow Integration: The integration of digital technologies into the dental workflow is revolutionizing the design, planning, and placement of titanium implants. Computer-aided design (CAD) and computer-aided manufacturing (CAM) software enable clinicians to digitally plan implant placement, design surgical guides, and fabricate custom implant restorations with high precision and accuracy. Digital impressions, cone-beam computed tomography (CBCT), and intraoral scanning technologies provide detailed anatomical information, allowing for virtual

implant placement and comprehensive treatment planning. The seamless integration of digital technologies streamlines the implant treatment process, improves treatment outcomes, and enhances patient satisfaction.[8,14,18,19]

2.1. Future Directions

Ongoing research in dental materials science aims to further enhance the properties and performance of titanium-based materials for dental applications. Surface modifications, such as coatings and textures, are being explored to improve the osseointegration of dental implants and enhance the longevity of prosthetic components. Advances in additive manufacturing techniques enable the fabrication of customized dental implants and prostheses with complex geometries, offering personalized solutions for patients. Furthermore, interdisciplinary collaborations between materials scientists, engineers, and dentists continue to drive innovation in dental biomaterials, paving the way for the development of novel titanium-based materials with tailored properties for specific clinical applications [20-24]

3. Conclusion

Titanium and its alloys play a vital role in modern dentistry, offering versatile solutions for various clinical challenges. From dental implants to orthodontic appliances and prosthetic components, titanium-based materials provide clinicians with reliable options that prioritize patient comfort, durability, and biocompatibility. As research and development efforts progress, titanium is expected to remain at the forefront of dental materials innovation, contributing to improved patient outcomes and advancements in oral healthcare.

Compliance with ethical standards

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Disclosure of Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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