Utilization of Nanomaterials In Prosthetic Dental Treatment

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Abstract

Nanomaterials in prosthetic dental treatments have garnered significant attention in the field of dentistry. These nanomaterials are utilized in various forms, such as nanoceramics, nanocomposites, nanoimplants, and antimicrobial nanoparticles. Particularly, through nanotechnology advancements, these materials offer high mechanical strength, biocompatibility, and aesthetic properties, enhancing the success of dental restorations and prosthetics. Additionally, nanoparticles with antimicrobial properties provide protection against periodontal diseases and tooth decay. The development of nanoparticle synthesis methods and techniques has enabled the use of more effective and safe materials in prosthetic dental treatments. The impact of nanotechnology in dentistry allows for the development of more successful and sustainable treatment options for patients.

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Introduction

Prosthetic dental treatment holds critical importance for restoring the function and aesthetics of missing teeth. In this field, the use of nanomaterials presents substantial potential, particularly due to materials with dimensions ranging from 1 to 100 nanometers (1). The biocompatibility, mechanical strength, tissue compatibility, and aesthetics of the materials used in this process are crucial for achieving successful results (2).

Nowadays, research in the field of nanotechnology evaluates the use of various nanomaterials, such as carbon nanotubes, nanocrystals, and nanofibers, in prosthetic dental treatment (3).

Nanomaterials significantly contribute to the development of biocompatible ceramics, polymers, and composites for prosthetic dental treatment. The nanoscale properties and performance of these materials assist in the production and application of more durable, aesthetic, and functional prostheses. Specifically, the integration of nanoscale ceramic particles into composite materials allows for the development of high-strength and aesthetically superior dental prostheses (4). Numerous studies have demonstrated that nanoparticles improve the biomechanical properties of polymer materials (5, 6). For instance, polymer materials prepared with the addition of nanotitanium dioxide (TiO_2) enhance mechanical strength, surface properties, thermal stability, and resistance to UV radiation (7). Additionally, the size, shape, and distribution of nanoparticles affect the color stability of prosthetic materials (8).

Nanoparticles represent a significant advancement in prosthetic dental treatment, particularly in the processing of materials in contact with oral mucosa. The antibacterial properties of nanoparticles reduce bacterial colonization of prosthetic materials in the oral cavity, thus lowering the risk of infection. Research has shown that the use of silver nanoparticles in prosthetic materials can reduce bacterial growth and biofilm formation (9). These features improve patient quality of life by extending implant success and lifespan (10).

However, there are potential risks and concerns associated with the use of nanomaterials in the field of dentistry. Considering the aging population and increasing dental health needs, progress in this field will become even more crucial in the future. Therefore, further research is needed on the biological interactions, toxicity profiles, and efficacy of materials at the nanoscale (10).

Materials and Methods

The main information sources are scientific databases such as PubMed, Scopus, Web of Science, and Google Scholar. In addition, books and conference papers related to the subject have also been reviewed. The scanning process has been performed using specific keywords and keyword combinations such as "prosthetic dental treatment", "nanomaterials", “nano composites”, “nano ceramics”, "nanotechnology", “nano resin”, “nano implant”,“nano coatings”, “antimicrobial nanoparticles”, "biomechanical properties”, “biocompatibility", "aesthetics" etc., to include English articles from 2013 to the present. According to this search data, 7160 studies were analyzed. 2846 studies were not included in the study because the full text could not be reached. 4264 studies that did not meet the research criteria were excluded. 50 studies were evaluated and included in the research.

Results

1.Nanoparticle Synthesis

Nanoparticles used in prosthetic dental treatment, which are generally a few hundred nanometers in size, can be composed of metal, metal oxide, or organic compounds. These substances can be synthesized through chemical or physical methods. Chemical methods typically involve dissolving metal ions in a solution and adding a reducing agent. This allows the metal ions to be reduced to nanoparticles through redox reactions. Physical methods, on the other hand, involve obtaining previously existing nanoparticles from a substance by mechanically or thermally reducing its size. The synthesis of nanoparticles is associated with numerous parameters, including the chemicals used, solvents, reducing agents, temperature, and pressure. For instance, the size of the nanoparticles can vary depending on the reaction temperature and the type of reducing agent used. The characterization of the resulting nanoparticles involves size, morphology, surface area, surface charge, chemical properties, and quantum properties (11) (12). The fundamental principles of nanoparticle synthesis include chemical or physical methods, liquid/gas phase reactions, precipitation methods, and microwave or ultrasonic methods (13). Among these methods, the most commonly used are sol-gel, hydrothermal, and precipitation methods (13).

The sol-gel method is a popular method for the synthesis of inorganic nanoparticles and allows for the production of homogeneous and versatile products using a controllable chemical reaction. Hydrothermal synthesis is a method performed under high temperature and pressure, and it is considered a suitable option for obtaining products with a crystalline structure (14). The precipitation method, on the other hand, is used to obtain nanoparticles synthesized by precipitating inorganic substances in solution and is particularly preferred for obtaining products with high purity and in large quantities (15).

Microwave synthesis, used for nanoparticle synthesis, is preferred due to the acceleration of chemical reactions by microwave energy (16). Ultrasonic methods are employed with the aim of controlling particle sizes and increasing homogeneity using high-frequency sound waves (17).

There are numerous methods available for nanoparticle synthesis in prosthetic dental treatment, and each method offers different advantages depending on the properties of the resulting products.

2.Nanomaterials

Nanomaterials used in dentistry can be examined in 6 classes as nanocomposites, nano hybrid resins, nano ceramics, nano implants, nano coatings, antimicrobial nanoparticles.

2.1.Nanocomposites

Nanocomposites are materials formed by the combination of inorganic filler particles at the nano-scale and an organic matrix (18). Nanocomposites typically comprise a resin matrix and nano-sized filler particles. The resin matrices are generally a methacrylate-based compound, such as bis-GMA (bisphenol A glycol dimethacrylate) or UDMA (urethane dimethacrylate). Bis-GMA and UDMA connect to each other during the polymerization process, forming a three-dimensional network structure. This network structure enhances the overall strength and durability of the composite material. Moreover, the low water absorption of these resins makes them more suitable for intraoral applications. The atomic structure of these materials consists of a regular crystal structure. Each atom is typically linked to other atoms in a specific geometric arrangement. This regular structure provides high hardness and strength to the nanoparticles. The atomic dimensions of these particles allow them to distribute homogeneously within the material and interact effectively with the resin matrix.The atomic structure of nanocomposites depends on the atomic structures of these two components and their interactions with each other. These interactions typically occur through different types of interatomic forces, such as chemical bonds, van der Waals forces, and hydrogen bonds. The nano-scale filler particles provide enhanced polymerization and mechanical durability due to the increased surface area and better interaction with the composite matrix (19). Additionally, the lower polymerization contraction of nanocomposites reduces stress formation during restoration, thus lowering the risk of secondary caries formation (20).

The optical properties of nanocomposites offer an aesthetic appearance closer to natural tooth tissue. Nano-scale filler particles render the light transmittance and scattering of composites more compatible with the properties of a natural tooth (21). Consequently, the natural color and brightness of teeth enable restorations to have a more natural appearance (22).

Antimicrobial properties are also among the advantages of nanocomposites. Studies incorporating silver nanoparticles into nanocomposites demonstrate that these materials can enhance antimicrobial activity, potentially extending the lifespan of restorations (23) (24).

However, nanocomposites have some disadvantages. Due to the higher surface area and reactivity of nanoparticles, excessive polymerization heat production and thermal damage to the restoration's surroundings may occur in some cases (25). Furthermore, the cost of nanocomposites is higher compared to traditional composites (26).

In the future, it is expected that the properties of nanocomposites will be further improved and costs will be reduced, allowing for more widespread and effective use of these materials in dental applications. Additionally, new nanoparticle types and functional nanostructures may enable restorations to possess properties such as higher biocompatibility, antimicrobial efficacy, and mechanical durability.

2.2.Nanohybrid Resins

Nanohybrid resins are modern restorative materials used in prosthetic dental treatments and developed with nanotechnology. These materials comprise a combination of micro filler particles and nano filler particles, offering enhanced mechanical, optical, and ease-of-handling properties (27). In terms of mechanical properties, nanohybrid resins provide higher strength and wear resistance compared to traditional composites (28). Nano filler particles increase the surface area of the composite and ensure better interaction with the matrix, resulting in higher compressive resistance and wear resistance (18). These properties are crucial for the long-term performance and durability of restorations.

Optically, nanohybrid resins are expected to deliver aesthetic outcomes similar to natural tooth structure. The light transmission and scattering properties of nanofillers render restorations closer to the color and brightness of adjacent natural teeth (29, 30).

Regarding ease of application, nanohybrid resins' lower polymerization contraction reduces stresses during restoration, lowering the risk of secondary caries formation (20). Moreover, the improved moldability and reduced stickiness of these materials allow dentists to complete the treatment process more comfortably and quickly (31).

The wear resistance and surface roughness of nanohybrid resins may vary depending on the type and proportion of filler particles used (32). However, disadvantages such as performance variations depending on cost and filler particles must be considered. Therefore, selecting the most appropriate material and treatment method for each patient is essential. Further clinical and laboratory studies on the use of nanohybrid resins in dental applications will help us better understand their potential advantages and limitations.

2.3. Nanoceramics

Nanoceramics are complex materials that contain a range of different ceramic components and are often preferred in prosthetic dental treatment applications. These components generally include nanoparticles of ceramic materials such as silica (SiO_2), alumina (Al_2O_3), titania (TiO_2), and zirconia (ZrO_2). The atomic structure of the components is arranged so that silicon, aluminum, titanium, zirconium atoms, and oxygen (O) atoms form a tetrahedral structure. Silica is usually used as the main component of the nanoceramic matrix. It is known for its excellent biocompatibility features and optical properties, making it an ideal choice for dental restorations. Silica particles also enhance the overall hardness and strength of the material. Alumina is often added to nanoceramics because it possesses high hardness and wear resistance features. This ensures the long-term durability and performance of nanoceramic restorations. Titania is added to nanoceramics to provide excellent biocompatibility, corrosion resistance, strength, and hardness. Zirconia is added to nanoceramics to provide high strength and hardness. Zirconia also provides excellent wear resistance to the material and helps the restorations to be long-lasting. The components of these nanoceramics are dispersed within a resin matrix. The resin matrix is a methacrylate-based compound, such as bis-GMA (bisphenol A glycol dimethacrylate) or UDMA (urethane dimethacrylate). This resin matrix holds the nano-ceramic particles together and gives them a specific shape. Nanoceramics possess higher strength and durability compared to traditional ceramics (33). The more homogeneous distribution of nanometer-sized ceramic particles and dense sintering prevent crack propagation, thereby increasing damage tolerance and providing higher mechanical durability (34). These properties are crucial for the long-term performance and durability of restorations used in prosthetic dental treatment. In terms of optical properties, nanoceramics are expected to provide aesthetic results similar to natural tooth structure. Nanoceramics that mimic natural teeth offer a closer appearance to the natural tooth color and brightness in restorations (35). Consequently, aesthetically satisfying outcomes can be achieved.

Regarding ease of processing, the low-temperature sintering properties of nanoceramics, along with their easy moldability and low adhesion, allow dental practitioners to complete the treatment process more comfortably and quickly, ensuring more accurate and well-fitting restorations (36).

Nanoceramics also have some disadvantages. In particular, the cost of such ceramics can be higher compared to traditional ceramics. Additionally, the complexity and sensitivity of the production process for nanoceramics may create challenges in quality control and compliance with standards (36).

2.4. Nanoimplants

Nanoimplants are an innovative type of dental implant used in prosthetic dental treatment and developed using nanotechnology. Nanoimplants accelerate the osseointegration process and shorten healing time through nanotopography and nanostructured coatings (37). These coatings, which involve the use of bone-like materials such as hydroxyapatite and biocalcium phosphate, establish a quicker and stronger connection with the surrounding bone, facilitating a successful treatment process (38). Additionally, the integration of bioactive molecules, such as antibacterial agents and growth factors, into the coatings reduces the risk of infection, supports bone regeneration, and helps prevent biofilm formation (39) (40).

Advancements in biomaterials have made it possible for next-generation nanoimplants to use not only titanium and titanium alloys but also ceramic and polymer-based materials (41).

While nanoimplants hold great potential in prosthetic dental treatment applications, it is important to continuously evaluate and analyze progress in this field. The clinical performance of next-generation implants should be assessed in conjunction with the determination of optimal surface properties, material selection, and advancements in coating technologies. Therefore, scientific research and clinical studies should continue to best utilize the potential of nanoimplants and achieve the best outcomes in prosthetic dental treatment applications (42). Further studies are needed regarding the production processes and costs of nanoimplants. Additionally, more information should be collected on the long-term success rates and safety profiles of these implants (41).

2.5. Nanocoatings

Nanocoatings used in prosthetic dental treatment serve to improve the surface properties of dental implants and other prosthetic materials. These coatings enhance treatment success by accelerating osseointegration, increasing biocompatibility, and reducing the risk of bacterial infection (43). The success of nanocoatings depends on factors such as surface properties, material selection, and application techniques. An ideal nanocoating should provide high biocompatibility, good mechanical properties, and antibacterial activity (44).

One type of nanocoating consists of titanium dioxide (TiO_2) nanoparticles. Due to the antibacterial properties and the ability to prevent biofilm formation of TiO_2 nanoparticles, these coatings help achieve successful results by improving the hygiene of dental implant surfaces (43).

Another significant type of nanocoating is hydroxyapatite (HA) nanocrystals. HA is preferred due to its similar chemical composition to the natural bone matrix and its demonstrated biocompatibility. HA nanocoatings support the osseointegration process by providing better cell adhesion and proliferation on implant surfaces (41).

Nanocoatings containing silver nanoparticles, colloidal silver, and other antimicrobial agents have been reported in studies to make the treatment process safer by reducing the risk of infection (45). Therefore, research on nanocoatings combined with antibacterial agents and drug delivery systems continues.

Graphene-based nanocoatings have also drawn attention in the field of prosthetic dental treatment. Graphene offers excellent mechanical properties, high conductivity, flexibility, biocompatibility, and antibacterial activity. These characteristics indicate that graphene-based nanocoatings could be a promising option for dental implants and other prosthetic applications (46).

2.6. Antimicrobial Nanoparticles

Antimicrobial nanoparticles are garnering increasing interest in the field of prosthetic dental treatment. These nanoparticles can be incorporated into materials used for dental restorations and implants with the aim of reducing infection risk and preventing bacterial colonization (47). This section will discuss the use of antimicrobial nanoparticles in prosthetic dental treatment and related studies.

Silver nanoparticles (AgNPs) are the most popular among antimicrobial nanoparticles. Silver nanoparticles exhibit broad-spectrum antimicrobial activity and are effective against both Gram-positive and Gram-negative bacteria (45). This property encourages the addition of AgNPs to materials used for dental implants and restorations to reduce the risk of infection (48).

Zinc oxide nanoparticles (ZnO NPs) are another nanomaterial that exhibits antimicrobial activity. By incorporating zinc oxide nanoparticles into materials used in dental prostheses and restorations, the antimicrobial properties of these products can be enhanced (49). ZnO NPs are particularly effective against bacteria species that cause tooth decay, and their addition to dental restoration materials provides a significant advantage (50).

Titanium dioxide nanoparticles (TiO_2 NPs) are another nanomaterial with antimicrobial effects. TiO_2 NPs display strong antimicrobial properties, particularly when exposed to ultraviolet (UV) light. Coatings of TiO_2 NPs applied to the surfaces of titanium alloys used in dental implants increase the implant's resistance to biofilm formation, reducing the risk of infection (43).

The use of antimicrobial nanoparticles can help achieve better results in prosthetic dental treatment. However, the biocompatibility and toxicity profiles of these nanoparticles should also be considered (48). Additionally, more research is needed on their short- and long-term effects.

Antimicrobial nanoparticles such as silver, zinc oxide, and titanium dioxide are being considered as ideal candidates for dental applications, including dental restorations and implants. The use of these nanomaterials is aimed at achieving better results in prosthetic dental treatment, particularly by preventing biofilm formation and controlling bacterial infections (47).

However, concerns related to biocompatibility, toxicity, and environmental impacts must also be considered when using antimicrobial nanoparticles (48). Therefore, it is essential to conduct comprehensive preclinical and clinical studies to ensure the safe and effective use of nanoparticles.

Furthermore, research is ongoing on next-generation nanomaterials and surface modification techniques to make antimicrobial nanoparticles more effective and safer for dental applications. These technologies can contribute to the development of more effective and sustainable antimicrobial strategies in dentistry.

In summary, the use of antimicrobial nanoparticles in prosthetic dental treatment offers new and effective antimicrobial strategies for dental restorations and implants. However, further research and clinical studies are needed to ensure the safe and effective use of this technology.

Discussion and Conclusion

This study has assessed the importance and potential benefits of using nanomaterials in prosthetic dental treatment. Nanomaterials contribute to the development of innovative and effective treatment approaches in dentistry. These materials, used in restorative treatments, implantology, and aesthetic dentistry, provide improved mechanical properties, biocompatibility, antimicrobial activity, and natural appearance.

Nanocomposite and nanohybrid resins offer strong and durable options for aesthetic restorations, while nano-filled particles provide optical properties similar to natural tooth structure. Nanoceramics and nanoimplants deliver more durable and long-lasting treatment outcomes, along with improved biomechanical compatibility and biological integration. Antimicrobial nanoparticles contribute to reducing infection risk, thereby increasing the chances of treatment success.

However, there are also some potential disadvantages associated with the use of nanomaterials. These disadvantages include cost, toxicity risks, and the unknown long-term effects. Therefore, more research and clinical studies will provide further information on the effectiveness, safety, and applicability of these materials.

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