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Review Article

Nano – Engineered Solutions: The Future of Prosthodontic Materials and Therapies

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ABSTRACT

Nanotechnology has revolutionized the landscape of modern dentistry, particularly in prosthodontics, by introducing nanoparticles (NPs) with multifunctional applications. This article explores the various types of nanoparticles used in prosthosdontics, their functional mechanisms, and their applications in dental materials such as acrylic resins, denture liners, adhesives, composites, dental cements, and implants. The benefits of using nanoparticles, including improved mechanical properties, antimicrobial action, and targeted drug delivery, are highlighted, along with a discussion on cytotoxicity and safety considerations. The article concludes by presenting the future prospects of nanotechnology in prosthodontics.

KEYWORDS

• Nanotechnology • Nanomaterials • Prosthodontics

INTRODUCTION

Nanotechnology is considered to be the 21st century current technology based on its economic and scientific potential which concerns the structures on a Nano scale. According to the British Standards Institution nanoparticles are defined by its particle size or diameter which is measured in nanoscale.[1] Nanoparticles are routinely defined as ultrafine units with dimensions between about 1 and

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100 nm (1 nm = 109 m) that show properties that are not found in bulk samples of the same material. Nanoparticles exist in the natural world and are also created as a result of human activities. Because of their submicroscopic size, they have unique material characteristics, and manufactured nanoparticles may find practical applications in a variety of areas, including medicine, engineering, catalysis and environmental remediation[2].

The interest in nanoparticles (NPs) and nanomaterials used in dentistry is rapidly increasing both in research and clinical settings. The development and testing of numerous nanomaterials in recent years have opened up new possibilities and solutions that were previously unavailable in the field of dentistry. This article aims to provide a comprehensive review of the current knowledge and understanding of NPs used in modern dentistry.

Applications for "nanodentistry," or the use of nanoparticles in dentistry, have been demonstrated for antibacterial action, anti-inflammatory, remineralization, osteoconductivity, and stem cell differentiation. In addition to being applied to dental tissues, nanoparticles have been employed to improve the mechanical characteristics of dental composites, lowering friction and strengthening bonding and anchoring.

Need for nano materials in dentistry

Even with the recent advancements in physical properties and the understanding of different materials and their chemical properties, no material can be considered optimal for use in dentistry. For instance, although composite materials are aesthetically pleasing, they lack mechanical qualities and are highly technique sensitive. No one artificial substance has the ability to react to outside stimuli and behave similarly to tissue found in nature. When it comes to either creating new materials or significantly enhancing existing ones, nanomaterials are surrounded by high spirits.[3]

Types of Nanoparticles and their Roles:

1. **Gold Nanoparticles (AuNPs):** Gold nanoparticles are used as antimicrobial delivery agents and coatings to enhance osseointegration of implants.AuNPs were utilized as osteoinductive agents by Heo *et al*.[4] to immobilize the titanium surfaces of dental implants. As osteoinductive agents for dental implants, gold nanoparticles on dental implant surfaces helped to stimulate bone growth and preserve nascent bone formation around dental implants.
2. **Titanium Dioxide (TiO_2) NPs:** TiO_2 exhibits photocatalytic activity that generates reactive oxygen species (ROS) for antimicrobial action. It enhances mechanical strength and bond properties in glass ionomers and resins. (*Figure* 1)

Figure 1: Titanium dioxide nanoparticles

3. **Silver Nanoparticles (AgNPs):** Silver's antimicrobial qualities have been known since antiquity. It has also been shown to have antifungal and antiviral properties. By deactivating enzymes that stop DNA replication, silver ions cause cell death in bacteria. Silver's antibacterial qualities have caught scientists' interest, and as a result, it has been utilised in dental materials. AgNPs disrupt bacterial membranes, impede DNA replication, and reduce biofilm formation. Their integration into composites and tissue conditioners improves antibacterial properties and reduces denture stomatitis risk.
4. **Copper NPs:** Copper NPs exhibit higher bactericidal activity than silver NPs but pose biocompatibility challenges due to potential toxicity. CuNPs attach to amine and carboxylic groups on the surface of the microorganism, destabilising the cell membrane and causing cell death[7]. Copper ion-generated free radicals can change the DNA replication and protein synthesis of microorganisms. (*Figure* 2)

Figure 2: Copper nanoparticles

5. **Zinc oxide NPs:** Zinc's antibacterial effectiveness is far higher at the nanoscale than it is at the macroscale. The bacterial cell membrane becomes more permeable in the presence of zincions, which causes the cell to die. Dental resin composites have been found to benefit from the mechanical and antibacterial features of cellulose nanocrystal and zinc oxide nanoparticle (ZnONP) nanohybrids, as revealed by Wangetal.[5] In dental materials, antibacterial properties of ZnONP scan be beneficial. (*Figure* 3)

Figure 3: Zinc oxide nanoparticles

6. **Aluminum oxide NPs:** Al_2O_3 NPs can improve the mechanical strength of inadequate dental materials. Low flexural strength and impact strength are two drawbacks of polymethyl methacrylate (PMMA). Adding Al_2O_3 NPs to a PMMA matrix significantly improved the resin's mechanical and thermal properties and reduced water absorption and solubility. (*Figure* 4)

Figure 4: Aluminum oxide nanoparticles

7. **Silicon dioxide NPs:** The mechanical properties of dental restorative materials can be enhanced by the use of silicon dioxide nanoparticles as filler. In order to maintain teeth clean and prevent food accumulation or plaque development, silica fine powder is used as a general dental polishing agent to smooth out uneven tooth surfaces. Most commonly found in nature as quartz, a form of SiO_2 NPs, is a silicon oxide with the chemical formula SiO_2, also known as silica. (*Figure* 5)

Figure 5: Silicone oxide nanoparticles

8. **Zirconium dioxide NPs:** The significance of zirconia, which has been utilised in dental materials for many years, cannot be overstated. Zirconia, frequently referred to as "ceramic steel," significantly surpasses the competition in terms of stiffness, capacity, fatigue resistance, high wear resistance, and biocompatibility. It is a great option for cosmetic purposes because of how closely it resembles the real tooth in terms of both colour and features. Enomoto *et al*.[6] revealed PMMA can be improved by using ZrO_2 NPs as a filler to reinforce the matrix. In terms of strength and resistance to bending, zirconia-based ceramics fared better than alumina ceramics. ZrO_2 NPs can be

used as a filler in dental nanocomposites by dentists to enhance the materials' mechanical characteristics, radio capacity, and aesthetic appeal. (*Figure* 6)

Figure 6: Zirconium oxide nanoparticles

Nanoparticles in Prosthodontics (*Table 1*)

Table 1: Tabulation of nanoparticles in Prosthodontics

Application Area	Nanoparticles Used	Functional Benefits
Acrylic Resins	TiO_2, ZrO_2, Ag	Enhances mechanical strength, color stability, and antimicrobial properties in PMMA resins.
Soft Liners & Tissue Conditioners	AgNPs	Improves antifungal activity; optimal efficacy below 80 ppm to avoid aggregation and maintain performance.
Denture Adhesives	Antimicrobial agents including NPs	Boosts retention, comfort, and reduces denture stomatitis through enhanced microbial resistance.
Composites	SiO_2, TiO_2, Alumina	Enhances aesthetics, flexural strength, and resistance to bacterial colonization.
Dental Cements	MgO, Ag	Provides strong antibacterial properties, reduces microleakage, and enhances mechanical integrity.
Dental Porcelain	Ag, ZrO_2	Increases fracture toughness and hardness via mechanisms such as crack bridging and transformation toughening.
Dental Implants	TiO_2, HAP, ZrO_2	Promotes osseointegration, antimicrobial activity, and osteoconductivity for implant longevity.
Maxillofacial Prosthesis	TiO_2, SiO_2, ZnO, Ag, ZrO_2	Improves color stability, mechanical strength, UV resistance, and reduces microbial colonization in silicone elastomers.

Titanium dioxide nanoparticles have been used as additives to biomaterials in order to induce antimicrobial properties. Antimicrobial activities of titanium dioxide against candida albicans, staphylococcus aureus, pseudomonas aeruginosa, escherichia coli, lactobacillus acidophilus, etc. have been proved by recent studies.[12] Recently, research has focused predominantly on nanoparticles, which are widely recognized as they are offering advantageous characteristics due to their size, shape, composition, and ability to enhance the existing properties of polymers. The emerging science and technology in the field of nanofillers are promising for the fabrication of PMMA polymer composites. A relatively new material called zirconium oxide (ZrO_2) also referred to as Zirconia hasgrown in popularity as it is a typical bioceramic and, therefore, exhibits a good bioactivity and biocompatibility. Zirconia also offers exceptional high flexural strength, fracture toughness and durability, in addition to good aesthetics. Another nanomaterial that has attracted significant interest is titanium oxide (TiO_2). TiO_2 offers suitable cost and mechanical properties, is chemically stable and is non-toxic.

Acrylic resin

The importance of acrylic resins in dentistry is evident. They are widely used in making temporary prosthetic base materials, provisional prosthesis, dentures and orthodontic removable appliances such as retainers and functional appliances. These resins commonly consist of methacrylates, especially poly methyl methacrylate (PMMA), and additional copolymers. The propensity for plaque accumulation caused by the food-retentive design and surface porosities of these removable acrylic appliances, which in turn promote the bacterial activity of cariogenic oral flora, is one of the main issues that patients and dentists frequently confront when using them.

Tissue Conditioners

The most frequent inflammatory response of the oral mucosa beneath a denture is called denture induced stomatitis. This disease has a multifactorial etiology. The chance of denture-induced stomatitis is significantly increased

by an ill-fitting denture, inadequate denture hygiene, and microbial colonization on the denture surface and surrounding oral mucosa.

Tissue conditioners and other soft lining materials work as drug delivery vehicles to deliver antiseptic agents and treat denture stomatitis. Nystatin and Amphoteracin B, two antifungal medications, are frequently used to treat denture stomatitis. Antifungal medications, on the other hand, have a human board spectrum target that physicians use to treat patients. Despite being effective antifungal medications, amphoteracin B and nystatin do not work well when added to viscogel tissue conditioners.[7] These days, a number of novel antifungal treatments are available, including metal nanoparticles included in soft lining materials, metallic oxide powders, and natural and herbal oils. Clinically, the adherence of tissue conditioner to acrylic resin is significant. In this study, there were three failure modes following de-bonding (TBS). According to Khumsup *et al*. (2017), anincrease in the concentration of silver nanoparticles led to a heightened rigidity and a reduction in both Water solubility and sorption. Consequently, the bonding surface between tissue conditioner and the acrylic resin denture base may be impacted by the harder tissue conditioner in high concentration groups.[7]

Denture Adhesive

Denture adhesives can increase stability and retention, which can provide patients greater psychological self-assurance, especially in public settings. Nevertheless, excessive amounts of denture adhesive should always be advised and denture adhesives should never be used to increase retention in an incorrectly made, ill-fitting denture. With its many advantages, nanotechnology has become a valuable tool in dentistry. The enhanced properties of nanoparticles in terms of chemistry, biology, and physical state are on par with or superior to those of traditional therapies. They offer reduced side effects, increased bioavailability, loaded therapeutic substances, and optimized pharmacological activity. A novel and promising approach to developing more effective pharmacological treatments that lessen microbial resistance and the cytotoxic effects of traditional antifungal therapies at the cellular level is the development of materials on a nanometric scale. Matalon *et al*.[8] showed that the addition of chlorhexidine to denture adhesive pastes inhibits the growth of *C. albicans*, although this inhibition decreases with time. Nevertheless, we believe that such an association may potentially reduce the incidence of DS. In the same context, Almeida *et al.* found that the combination of antimicrobial phytotherapies with COREGA® powder adhesive amplified the potential of the material on the heat-cured resin surface, with similar results to the control using nystatin. Other compounds, including fluconazole, nystatin, miconazole, antimicrobial lipids, and peptides, were also associated with denture adhesives and resulted in antimicrobial effects against different strains of Candida.[8]

Composites

In order to address issues including polymerization shrinkage, wear resistance, and microhardness, as well as to enhance the physical and cosmetic qualities of dental composites, the usage of nanoparticles has grown. Nano-hybrid and nano-filled composites with fillers in different amounts (1-100 nm, 20-600 nm) are the most commonly utilized resin nanocomposites. The majority of the particles in nanofillers are between 1 and 100 mm in size, but the larger particles in nano-hybrids range from 0.4 to 5 um. Alumina nanoparticle addition raises the nanocomposite's hardness in comparison to other nanocomposites, per a study by M. Al Haik *et al*. An inexpensive plasma torch is used to create alumina nanoparticles.[9] In a work by G. Polizos, titanium dioxide nanoparticles were created in an aqueous solution. They were distributed throughout a matrix of epoxy polymers. Better mechanical qualities were displayed by the resultant material.[10] In a work by Zhanhu Guo *et al*., alumina nanoparticles were functionalised with a bi-functional silane surfactant using a simple technique. Both modulus and strength significantly increased as a result.[11]

Dental Cements

While conventional and resin-modified glass ionomer cements offer advantages

like fluoride release and tooth structure remineralization in the oral environment, they also have drawbacks including inadequate bond strength, mechanical qualities, and aesthetics. Glass ionomer can have chitosan, HA, fluorapatite, TiO_2, SiO_2, and ZrO_2 nanoparticles added to it to enhance its visual qualities.[12] Fluor aluminosilicate nanoparticle-containing resin-modified glass ionomers are frequently employed in clinical settings. When 15% SiO_2 nanofillers in the size of 40 nm were added to the ionomer in a novel nanomaterial, improved wear resistance and a shorter curing time were noted[13]. While Ibrahim *et al*.[14] demonstrated that the addition of TiO_2 nanoparticles demonstrated antimicrobial activity with biofilm inhibition and improved certain physical properties, Kumar *et al*.[15] demonstrated that the addition of 10% by weight chitosan nanoparticles to the glass ionomer cement increased the material's resistance and the release of fluoride.

Dental Porcelain

Compared to metal alloys, ceramics have grown more and more popular in prosthetic dentistry as restorative materials because of its aesthetic qualities, chemical stability, biocompatibility, reduced plaque accumulation, low heat conductivity, and radioactivity. Because dental porcelains used for ceramic restorations are brittle, it may be required to replace restorations that are chipped or fractured. Because porcelain is brittle and deforms elastically rather than plastically, restorations may chip or break. Studies on reinforcing dental ceramics by altering their microstructure have been conducted over the past 20 years, and several ceramic materials have been created by including particles of varying sizes into the material composition. In recent years, ceramics have been developed using nanoparticles. Tokushi *et al*. added precious metal nanoparticles to commercial porcelain, they increased the material's fracture toughness and Young's modulus, thereby improving its mechanical qualities[16]. The porcelain's vickers hardness and fracture toughness were greatly enhanced by the inclusion of silver nanoparticles. In a study, Tokushifujieda *et al*. added silver and platinum nanoparticles, two precious metals, to dental porcelain. They concluded that this improved the mechanical qualities of the porcelain.[17]

Dental Implants

Nanotechnology can be used to cover dental implants with different types of nanoparticles. In implant-supported prostheses, the gold standard for treating tooth loss, the surface of the implant is essential to guaranteeing biocompatibility and osteointegration. By enhancing vascularity in cortical bone, coating the implants with pharmacological nanoparticles like nano TiO_2, HA, calcium phosphate, calcium silicate, C, and bisphosphonates promotes cell differentiation and proliferation and can create an environment that is conducive to both early and long-term bone formation.[18] Nano-HA is the most popular nanocoating for dental implants because it resembles the inorganic components of bone. Better bone growth, osteointegration, and bone-implant contact were demonstrated by implants with nano-HA surfaces. After six and twelve weeks of implantation, Yang *et al*. assessed the impact of titanium implants coated with nano-HA on osseointegration and demonstrated that HA nanoparticles promoted osteointegration. Antibacterial nanoparticles of copper, bismuth, and silver (Ag) are used to treat and prevent perimplantitis.[19] By drastically lowering microbial adhesion, roughness, and chemical weathering on implants, TiO_2 nanoparticles considerably lower the quantity of bacteria affixed to the implant surface.

Impression Materials

Biocompatibility, hydrophilia, dimensional stability, elasticity, and an appropriate density with enough fluidity to produce details are all desirable qualities in an impression material. Nanoparticles can be added to the impression materials to give them these qualities as well as to enhance their mechanical and physical characteristics. When compared to traditional polyvinylsiloxanes, the inclusion of nanoparticles to these impression making materials enhances their hydrophilic qualities, fluidity, and clarity. It has greater fluidity, resistance to deterioration, and strong tear resistance. Heat resistance and the slip-cast feature lessen the inaccuracies brought on by movements during the impression process. Cross-infections can be avoided thanks to the antibacterial qualities of impression materials like alginate. Because of their antimicrobial

qualities, nano-Ag particles can be incorporated into impression materials. According to Omidkhoda *et al*., adding 500 ppm and 1000 ppm concentrations of Ag nanoparticles to the alginate material decreased but did not entirely stop the growth of E. coli, S. aureus, and C. albicans on the alginate surface.[20]

Maxillofacial Prosthesis

Numerous synthetic materials, including silicone, polyvinyl chloride, polymethyl methacrylate, polyurethanes, and chlorinated polyethylene, are used to make maxillofacial prosthesis. While silicones have many advantages, including acceptable tear, tensile strength, high mechanical strength, and ease of production, they also have drawbacks, including discolouration, deterioration of their mechanical and physical properties, and repair challenges, as well as short usage times and contamination. To address these issues, silicones can be made stronger and more flexible by adding a lot of nanoparticles. Ag nanoparticles were added to the materials because of their antibacterial qualities, and it was found that this stopped Candida albicans from sticking to the prosthetics' surface. The mobility of facial components including the lips, nose, and eyes makes silicone elastomers extremely prone to ripping. For optimal face prostheses, the inclusion of nano-sized Ti, Zn, or Ce oxides at weight concentrations of 2.0–2.5% raises the tensile strength, stretching percentage, and rip resistance.[21] When exposed to ultraviolet (UV) radiation, polymer molecules deteriorate, break apart, and undergo shape changes because they are more susceptible to this type of light. UV shields are mostly made of nanoscale ZnO and Ti_2O. The colour stability of pigmented maxillofacial silicone elastomer was investigated by Han Y. *et al*.[22] TiO_2, CeO_2, and ZnO were employed as opacifiers for the silicone elastomer, and they produced the least amount of colour change.

Cytotoxicity and Exposure of Nanoparticles

The study of the harmful effects of artificial nanostructures and devices on living things is known as nanotoxicology. A higher rate of absorption of non-biodegradable nanoparticles by the skin, lungs, etc. has been linked in studies to increased cardiovascular mortality, other extra pulmonary consequences, tissue damage, and systemic effects. The harmful effects of silver nanoparticles on the environment and human health are intolerable. Chronic exposure to silver has negative effects that include liver and kidney damage, as well as a permanent bluish-grey discolouration of the skin (argyria) and eyes (argyrosis).

Occupational exposure in the dental laboratory

When materials are processed, ground, and polished in a dental laboratory, such as when gypsum or investment materials are powdered, or when metals, resins, or ceramics are ground and polished, nanoparticles are liberated. The route of exposure and the prime target are the lungs of dental laboratory personnel. It is well-known that under adverse and old-fashioned technical conditions dental technicians are prone to pneumoconiosis, a chronic lung condition marked by fibrosis and mixed restrictive obstructive lung disease. However, the exposure to nanoparticles is as far as we know today is not known to induce increased rates of lung diseases, especially lung cancer to dental laboratory personnel. Special legal regulations for occupational safety are available for different countries.

Future perspectives

Generally speaking, nanotechnology ought to provide answers and "go green" in terms of safety and health. The potential advantages of green nanotechnology should be carefully weighed against any potential drawbacks for society, such as hazards to the environment, public health, and occupational safety. As a result, there will be financial and health savings as well as maximum environmental and societal benefits. Commercial applications of nanoparticles for the "real" regeneration of the periodontal apparatus as a whole, which includes dentine, cementum, periodontal ligaments, and bone, can be clarified with the help of recently produced nanomaterials and nanotechnology. In order to encourage the development of host tissues in animals, tissue engineering triads and scaffolds impregnated with nanoparticles can mimic an extracellular matrix. As a result, they are ideal for a variety of dental applications due to their low toxicity, antibacterial qualities, and improved protein-surface interactions. The idea of employing these materials to produce novel and enhanced biomaterials in a number of ways excites their dentists. Dental care could be enhanced by developments in nanotechnology

and the enhancement of traditional treatment approaches.

CONCLUSION

For a number of present and upcoming dental applications, nanomaterials have demonstrated encouraging results. With the use of nanotechnology, scientists were able to produce new materials and improve the mechanical and physical properties of existing ones. For instance, nanoparticles can boost the surface area for cell adhesion in tissue engineering scaffolds and fortify polymer composites. This field is getting a lot of money and has a lot of current research going on all over the world. The discovery and development of novel nanomaterials will probably result in significant improvements to dental materials research. In the upcoming ten years, it is anticipated that promising nanomaterials will provide a variety of dental materials.

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