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Nanomaterials and their application in Prosthetic Dentistry: A Comprehensive Literature Review

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ABSTRACT

The effects of nanotechnology are profoundly found in every aspect of science and development. Particularly, the field of dentistry is being influenced by nanotechnology making use of its immense potential. It is believed that nearly in the future, the advancement in the medical realm and the introduction of scientific devices that are tiny than dust mites may be one day capable of impressive medical miracles. However, the recent upsurge in the medical field, such as microscopy has given scientists new tools to understand and take advantage of these pre-existing natural phenomena when the matter is organized at the nanoscale. These Nanoparticles can be easily manipulated for surface chemistry, bonding capability when compared with bulk material and are overpowering.

The application of nanotechnology in dental sciences leads to the emergence of Nanodentistry which involves the maintenance of good oral health while using different biotechnologies and Nanomaterials with enhanced physical properties and antimicrobial potential. A variety of nanostructures such as nanofibre, nanorobotics,etc., have been considered for various applications in dentistry. Nanomaterials were included in a variety of oral health care products in the field of preventive dentistry and have been exploited in the development of restorative material. Nanomaterials have improved the treatment protocol in all important fields of dentistry such as endodontics, periodontics, tissue regeneration, implants, maxillofacial prosthetics, and restorative dentistry.

This review article is an attempt to provide a brief introduction and historical background regarding nanotechnology, an overarching view on Nanomaterials, and its application in the field of Prosthodontics.

Keywords: Nanoparticles, nanomaterials, prosthetic dentistry, silver nanoparticle, Nanoscience

1. INTRODUCTION

The design, characterization, and utilization of systems, devices, and structures by manipulating size as well as shape at the nanoscale (1nm to 100nm) is known as nanotechnology. It is a brand-new, cross-cultural and transnational scientific advancement that is quickly expanding and revolutionizing a number of fields, including manufacturing, research, product development, and commerce[1].Quantum size effect, surface effect, small size effect, and high surface energy are the four distinct effects of nanomaterials, along with their large surface area, high surface atom content, and small size[2]. Silver nanoparticles are among the many types of nanoparticles that have attracted the greatest attention recently[3].AgNPs (Silver Nanoparticles) typically have diameters of less than 100nm and contain between 20 and 15000 silver atoms. Even at the lower concentrations, AgNPs depicts a remarkable antibacterial activity due to their large surface-to-volume ratio[4].Prosthodontics is a significant area of dentistry that focuses primarily on treating dental defects, replacing lost teeth with crowns, veneers, and dentures, as well as using artificial prostheses to treat temporomandibular joint disease, periodontal diseases, and defects affecting the maxillofacial tissues. The primary goal of dentures is to maintain the wearer's health by restoring dental function and facial appearance. Denture materials can be broadly categorized into three types: metal, ceramic, and resin. The prosthesis, which comes into direct contact with the oral mucosa, is made with these materials, which are crucial. Since dental prostheses are used for extended periods of time in the oral environment, they require comprehensive properties and good biological activity. Chemical stability—that is, resistance to aging, corrosion, and fracture—is also essential. Nanoparticles provide greater efficacy and they can increase the self-life of any material because of that they were added to several materials like ceramics, acrylic resins, composite, dental cement, implants, maxillofacial prosthetic material, etc[5].

2. HISTORICAL BACKGROUND

The word "Nano" comes from the Greek word "Dwarf." Richard Feynman first suggested thenanotechnology idea at the California Institute of Technology when he presented his conceptual theory "There's Plenty Of Room AtThe Bottom," which that has been later published in "Engineering and Science"[6].Prof. Norio Taniguchi coined the term "nanotechnology" or "nanoscience" and first used it in 1974[7] Direct manipulation of individual atoms was suggested by Richard Feynman as a more potent method of synthetic chemistry[8].The first nanocomposites were introduced by Filtek Supreme in 2002[9]

3. CLASSIFICATIONS OF NANOMATERIALS

Nanomaterials classified into several groups. Simple and most commonly used classification is[10]:

	Classification	Examples
A. “Based on morphology	• Nanoclusters • Nanofibers • Nanowires/tubes • Nanoparticles	Electrospun polymers/silk Carbon-based Nanomaterials HA, Silica, silver, gold
B. Based on materials chemistry	• Carbon-based Nanomaterials • Polymer Nanomaterials • Metallic Nanomaterials • Nanoceramics • Nanocomposites	Fullerenes nanotubes Electrospun silk Nanofibres nanosilver Silica, Nanogold, titanium oxide, and HA Nanoparticles Silica/resin nanocomposites Ceramic/polymer nanocomposites”
C. Based on dimensions	• Zero-dimensional • 1-D • 2-D • 3-D	Nanoclusters Nanowires and nanotubes Nanolayer/films coatings Tissue engineering scaffolds polymers or composites

4. NANOPARTICLES USED IN DENTISTRY

Several nanoparticles are used in dentistry to increase the accuracy and life acceptancy of treatment. In dentistry, the most often utilized nanoparticles are:

Carbon nanotubes are primarily utilized in the materials used in dental fillings. increases the surface area of live cells by bringing active agents to them. These nanoparticles also stick well to the surfaces of teeth, dentin, and cementum, but under certain circumstances, their ability to cross membrane barriers can cause fibrotic and inflammatory reactions[11].

Graphene: It is appropriate for implantation, coating teeth, and reducing biofilm. This material is low-density, fracture-resistant, and cost-effective. It treats bacterial biofilm and forms a homogeneous crystal lattice. Metallic impurities may be incorporated into graphene post-synthesis processing steps, which could result in varying toxicity responses[12].

Hydroxyapatite (HAp): It functions as a cavity filler, lessens dental hypersensitivity, delays demineralization, and aids in enamel surface restoration. The dental tubules can readily absorb the nano-sized HAp particles. Adsorbed to the tooth enamel, biocompatible, and having a similar composition to that of teeth and bone, it protects teeth by creating a film of artificial enamel around them and corrects periodontal deficiencies[13].

Zirconia: It reduces the bacterial adhesion to the surface of the tooth, protects dental carries and it is an effective polishing agents[14].

Silica: It is used as a dental filling and polishing agent. Silica is an antibacterial agent so also used to treat dental hypersensitivity[15].

Titania: It is used for surface modification which provides more advantages like less bacterial adhesion and improved hardness. Because of this feature, it is mainly used in dental implants[16].

Silver: Silver is known to decrease bacterial colonization which improves oral health. Because of its antibacterial properties, it is used in dental restorative, prosthetic, and implants material[17].

5. ADVANTAGES OF USING NANOPARTICLES IN DENTISTRY

1. They promise a big surface area.
2. When antimicrobial agent-loaded nanoparticles are integrated into resin composites, they can exhibit antimicrobial, antiviral, and antifungal characteristics, which can subsequently inhibit the formation of biofilms.
3. They improve the dental material's mechanical qualities, particularly in restorative dentistry.
4. They strengthen the dentin's bond with the biomaterial.
5. They stop white spot lesions and crack propagation.
6. They increase the porcelain restoration's resistance to fracture[18].

6. APPROACHES OF NANOPARTICLES IN DENTISTRY:

Numerous nanotechnology techniques are being applied in dentistry for a variety of useful purposes. Nanomanufacturing can be approached from two basic perspectives. The process of producing materials, structures, and devices at the nanoscale on a large scale with dependability and economy of scale is known as nanomanufacturing.

1. Top-down approach:Using this method, larger devices are used to guide the assembly of smaller ones. Therefore, larger materials are patterned first, then smaller materials are carved down to create precise patterns in nanoscale structures[19].
2. Bottom-up approach:This method aims to put smaller parts together into a more intricate assembly. The dental process that is used includes endodontic regeneration, orthodontic treatment, oral cancer diagnosis, replacement of the whole tooth, hypersensitivity cure, nanorobotics dentifrice, and nanotoothpaste[20].
3. Functional approach:This method develops the desired functionality's components without considering how they might be put together.

The top-down approach is a destructive approach which describes the reduction of bulk materials to the particles of the nano-scale, whereas the bottom-up technique is a constructive approach which describes the creation of material from the atoms to clusters to the nanomaterials. These are the main distinctions between the two approaches[21].

7. APPLICATION OF NANOPARTICLES IN PROSTHETIC DENTISTRY:

Nanoparticles are used in almost every branch of prosthetic dentistry. The applications of nanoparticles in prosthetic dentistry are elucidated through the graphic diagram and in detailed as follows:

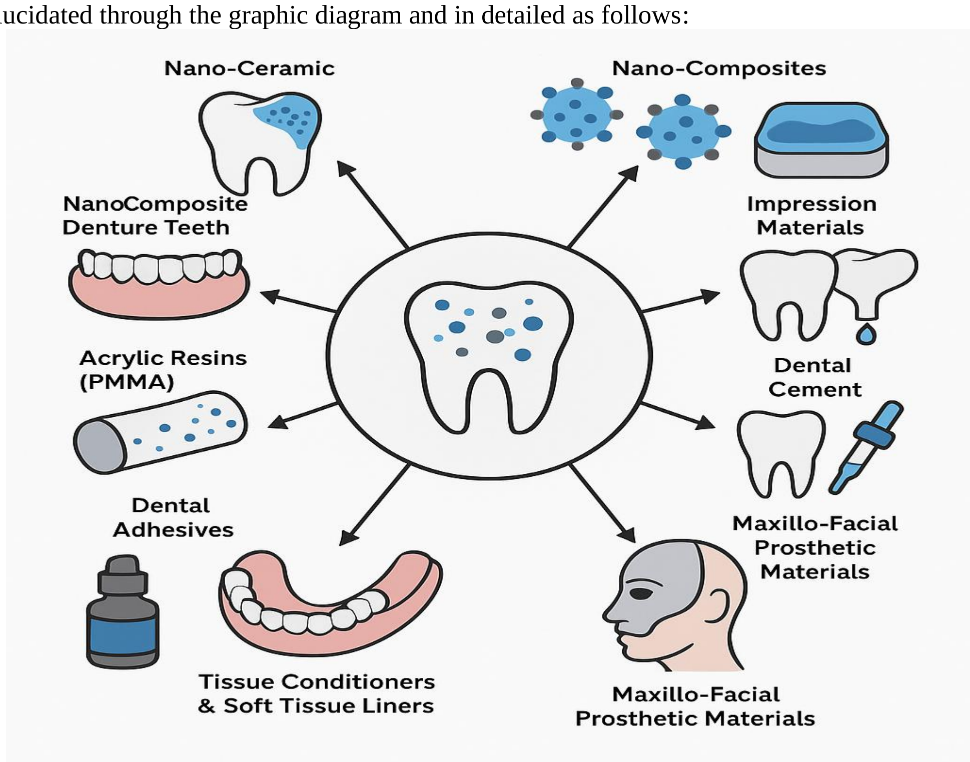

Figure No.1: Application of Nanoparticles in Prosthetic dentistry

Nano-ceramic

Ceramic restoration carried out using dental porcelains necessitates replacement either due to fracture or restoration. Because porcelain is brittle and deforms elastically rather than plastically, restorations may chip or break. Nanoceramics have demonstrated enhanced properties like toughness, ductility, and strength when compared to traditional ceramics. In order to find out if adding silver nanoparticles to dental porcelain could toughen it, Mitsunori Uno et al. conducted a study. The porcelain's Vickers hardness and fracture toughness both dramatically increased with the addition of silver nanoparticles[22].When made using the zirconia-silica sol-gel method, nanoglass ceramics have demonstrated excellent corrosion resistance, good translucency, low modulus of elasticity, and a higher hardness[23].When compared to conventional TiO2 ceramics, nano TiO2 ceramics have demonstrated increased toughness and hardness[24].Lava Ultimate Resin Nano Ceramic RNC Blocks (3M ESPE) are cutting-edge new CAD/CAM materials that offer exceptional durability, strength, and aesthetic appeal[25].

Nano-Composites

Composites with Nano-Fills To create nanocomposites, 1-100 nm nanofillers have been mixed into the resin matrix. There have been two different kinds of nanoparticles used: nanomers and nanoclusters.

NANOMERS: These are silica particles that are non-aggregated, monodispersed, and non-agglomerated that have been treated with 3-methacryloxy-propyltrimethoxysilane (MPTS). During the curing process, MPTS has aided in the nanomer filler chemical bonding to the resin. Excellent optical qualities, a higher polish & polish retention rate, flexural strength, superior hardness, and good aesthetics are all possessed by nanomers[26].

NANOCLUSTERS**:**The size of nanocluster fillers is 2–20nm. They have been formed by carefully sintering nanomeric oxides to form clusters with the precise distribution of particle sizes. It has been possible to create mixed oxides of zirconia and silica as well as purely silica sol nanoclusters. Although they have demonstrated similar benefits as nanomers with superior rheological characteristics, the drawback of inadequate handling has remained. Hybrid Nanostructures Nanomers have been combined with pre-polymerized organic fillers to enhance the intended rheological characteristics of composite materials[26].

TIO2 Reinforced Resin-Based Composite: Composites have benefited from the application of organosilaneallytriethoxysilane (ATES)-treated titanium dioxide nanoparticles to increase their flexural strength and microhardness.

Nanocomposites With Alumina Nanoparticles: Increases in the hardness, strength, and elastic modulus of nanocomposites have been observed with the addition of alumina nanoparticles.

Calcium Phosphate and Calcium Fluoride Nanoparticles Based Composites: Composites contain materials which release Ca phosphate and Ca fluoride because they have demonstrated the tooth structure remineralization. They have also been referred to as "smart" materials because they have prevented secondary caries by maintaining the levels of P and Ca ion release through release and recharge.

The natural components of human enamel have been mimicked by nanohydroxyapatites (HAP) with a 20 nm size, and they have demonstrated an anti-caries repair effect.

Ormocers (Organically Modified Ceramics): The polysiloxane backbone of these nanoparticles is utilized in glass and ceramic applications. For shade, pigments such as titanium oxide, iron oxide, and aluminum sulfo silicate hadbeen thenadded. The spread of microcracks has been stopped by these nanoceramic particles. Ceram X mono (DENTSPLY) is the commercially available version of it[26].

Nano-Composite Denture Teeth: Polymethyl methacrylate and uniformly distributed nanofillers are used in nanocomposite denture teeth. They have demonstrated greater abrasion resistance, enhanced shear strength, elevated durability and polishability, and superior aesthetics.

Impression Materials

Vinylpolysiloxanes, an addition-reaction silicone elastomer impression material, incorporates nanofillers to create a material with improved flow, hydrophilic qualities, and fewer voids at the margin, as well as improved model pouring with increased detail precision[27].

In comparison to the original viscosity, these silicone impression materials filled with nanoparticles have demonstrated a high degree of fluidity. Its purpose is to provide a snap set with reduced micromovement errors[28].

Dental Cement

Since silver has long been known to have bactericidal qualities, it is used in dental cement to inhibit microbial activity after crown and bridge cementation. A resin composite cement with materials containing silver was shown by Yoshida et al. to have favorable mechanical properties and a long-term inhibitory effect against S. mutans[29].Increases in compressive strength, flexural strength, fracture toughness, and antimicrobial activity have been demonstrated by GIC containing up to 5percent w/w TiO_2nanoparticles[30].Additionally, adding 5% TiO_2 nanotubes to an extracellular matrix greatly increased its noncollagenous composition, improving its microhardness and release of fluoride without changing the roughness of the surface. As a result, it may be used for restorations in greater stress-bearing sites[31].

GIC is a prosthodontic material that uses hydroxyapatite/fluoro-aluminosilicate technology. Its notably high compressive, tensile, and biaxial flexural strengths have made it useful for core build-up[32].New nano-filled resin-modified GIC containing 65% nanofillers has been used to fill in minor cavities in permanent teeth and restore primary teeth[33].Because it has better physiochemical and biological qualities than unreinforced cement without sacrificing cellular viability, TiO2 nanotube-reinforced self-adhesive resin cement had been utilized by luting indirect dental restorations[34].By adding ZnO and MgO nanoparticles, zinc polycarboxylate's compressive as well as tensile strength had been improved[35].

Acrylic Resins (PMMA)

TiO_2 and Fe_2O_3 nanoparticles, which have a lower porosity and a higher molecular weight, are added to polymethyl methacrylate. They are non-cytotoxic to mammalian cell culture and have the ability to stop Candida albicans from adhering. A significant problem with removable acrylic appliances is their tendency to retain food particles and accumulate plaque due to the presence of porous surfaces. This, in turn, increases the activity of bacteria that cause tooth decay in the mouth. Titanium dioxide nanoparticles are incorporated into dental materials to inhibit microbial activity[36].Because of its broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative bacteria, fungi, protozoa, etc., silver has attracted a lot of attention to its use[37].Because of their tiny size, silver nanoparticles produce a large area of oxidation and have a greater dispersion in the PMMA matrix. The antibacterial mechanism of nanoparticles is largely attributed to the release of silver ions, which cause microbial death by rupturing the wall of the cell causing denaturation of the protein, and blocking respiration of the cell[38].

Since denture teeth are somewhat frequently used, their wear resistance is their most desired physical characteristic. The denture teeth made of porcelain are the most resilient to wear, but they are fragile and don't bond well to the denture base. Increased abrasion resistance, a decrease in sorption as well as tensile and fatigue strength, solubility, and porosity, are the results of adding zirconium dioxide nanoparticles to heat-cured PMMA. On the other hand, as nano zirconium oxide has increased, translucency has decreased[39].Carbon nanotubes have improved the mechanical properties and reduced polymerization shrinkage when added to heat-cured monomer[40].In a similar vein, the addition of nanoparticles such as iron, silver, platinum, and titanium has been demonstrated to improve biomolecular adhesion, surface hydrophobicity, flexural strength, and porosity reduction[41].Adding 2% or 5% nano zirconium oxide has been shown by Gad et al. to improve the dentures' transverse strength that has been repaired using auto-polymerized resin[42].

Dental Adhesives

These are the substances that have been utilized to encourage cohesion or adhesion between two materials or between a material & natural structure of teeth. To strengthen the cohesiveness of the dental adhesive, polymerizable silane is added. Because the dental adhesive liquid is not very viscous, filler particles in it tend to settle out at the time of the storage, which causes inconsistent performance. Discrete silane-treated silica or zirconia nanoparticles, with sizes ranging from 5 - 7nm, are mixed with the dental adhesive to get around this drawback[43].

Tissue Conditioners & Soft tissue liners

Tissue conditioners are frequently utilized to improve denture-bearing tissues' ability to recover from damage, trauma, and residual ridge resorption—all of which are typically brought on by improperly fitting dentures. But over time, these materials deteriorate and become vulnerable to microbial colonization[44].Tissue conditioners are supplemented with AgNPsto address this issue. Following a 24-hour incubation period, the addition of AgNPsto these materials demonstrated antimicrobial properties against S. mutans and S. aureus at 0.1percent and C. albicans at 0.5percent[45].On silicone soft liners and obturators, solutions of chlorhexidine combined with trimetaphosphate, sodium triphosphate,or hexametaphosphate have been then tested for their antifungal properties. However, the chlorhexidine-HMP coating was found to be the most efficient antifungal agent, extending the prosthesis' lifespan[46].

Maxillo-facial Prosthetic Materials

Maxillofacial prostheses are devices utilized to replace facial parts lost due to illness or trauma. They have been constructed of silicone or other artificial substitutes. In addition, they help preserve and repair tissue health as well as enhance appearance to increase societal acceptance of facial injuries[47].By adding silver nanoparticles to maxillofacial prostheses, candida albicans are unable to adhere to the prosthesis surface and are not harmful to human dermal fibroblast cells[48].Nano titanium dioxide, cerium dioxide, and zinc oxide were used as opacifiers for silicone elastomer in a research by Han Y. et al. on the color stability of pigmented maxillofacial silicone elastomer; TiO_2 and cerium dioxide showed the least amount of color changes[49].The mechanical properties, particularly the tear strength, have improved with the addition of 3% concentration of silicon dioxide nanoparticles that have been surface-treated.

Dental Implant Materials

Surgically replacing one or more missing teeth by fusion of the bone to serve as an orthodontic anchor or a buttress for the placement of a crown bridge, denture, or other facial prosthesis, a dental implant is also referred to as an endosteal implant. Since a dental implant's surface is in direct contact with tissues and influences biocompatibility and biointegration, coating dental implants with biocompatible nanoparticles is one way to apply nanotechnology to dental implants. It is possible to significantly change how proteins interact with surfaces by modifying nanoscale topography. The rate of osseointegration is influenced by surface profiles in the nanoscale range, which are crucial for protein adsorption and osteoblastic cell adhesion. On nanostructured surfaces, vitronectin adsorption is higher than on conventional surfaces. When compared to other cell types, like fibroblast, this results in increased osteoblast adhesion on the nanosurfaces[50].

Implants coated with nanostructured hydroxyapatite (HA) have been shown to enhance osteoblast formation, including adhesion, proliferation, and mineralization[51]On titanium alloy implants, dual-layered silver-hydroxyapatite nanocoating has produced an antibiofilm surface without sacrificing the biocompatible HA surface necessary for good osteointegration and quick bone healing[52].Aluminum has become anodized due to the use of nanoporous ceramic implant coatings[53].Osseo-inductive activity has been made possible by this nanoporous alumina. The osseoconductivity of implants has been enhanced by calcium phosphate (CaP) coating, which has also demonstrated effective slow delivery systems for thefactors of growth and other bioactive molecules[54].

8. FUTURE OF NANOPARTICLES IN DENTISTRY

Nanotechnology appears to have a bright future in terms of:

1. Materials with nanotechnology for diverse dental applications
2. A nanovector for delivering genes to stimulate mandibular growth additionally
3. Nanomechanical sensors.

Furthermore, these can be built into the bases of orthodontic brackets and tubes to monitor treatment and provide real-time feedback regarding the orthodontic force being applied by the clinician[55].

In this field, biomimetic dental implants might be the next big thing to happen. Depending on the situation, different biomimetic coatings may be beneficial for use with specific patients. By covering implants with hydroxyapatite, nanotextured titanium, and pharmaceuticals like bisphosphonates, for instance, it may be possible to encourage increased vascularity and cell differentiation in highly cortical bone, which will improve the environment for both short- and long-term bone remodeling[56]

Calcium phosphate apatite crystals precipitated from simulated body fluids (SBFs) onto the titanium surface in a biomimetic manner to form a coating on titanium dental implants at room temperature[57].Biologically active medication introduction: To promote localized bone healing, the titanium dental implants surface might be covered with growth factors or other bone-stimulating agents. Several highly promising candidates for this purpose are members of the Transforming Growth Factors (TGFs) superfamily, specifically Bone Morphogenic Proteins (BMPs), Platelet-Derived Growth Factor (PDGF), TGF-beta1, and Insulin-like Growth Factors (IGF-1 and 2).

9. CONCLUSION

The science of nanotechnology is relatively new and is advancing quickly. It holds great promise for the efficient creation of new tools and nanomaterials that can be applied to the management of human health. It is anticipated that it will alter every aspect of healthcare management, including medication delivery, diagnosis, and prevention. they not only provide an alternative for treatment but also some superior approaches to the prevention of diseases with the help of simple techniques and biocompatible materials.

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