Review Article

University J Dent Scie 2025; Vol. 11, Issue 2

Nanotechnology in Prosthodontics

Abstract:
Nanotechnology has emerged as a transformative force in dentistry, particularly in the field of Prosthodontics, by enabling the development of materials with enhanced mechanical, physical, and biological properties. This article provides a comprehensive overview of the applications, classification, and implications of nanomaterials in Prosthodontic practice. It explores the integration of nanoparticles in various dental materials such as acrylic resins, impression materials, tissue conditioners, denture teeth, adhesives, coatings agents, implants, bone grafts, and maxillofacial prostheses. These nanomaterial-based enhancements offer improved strength, biocompatibility, esthetics, and antimicrobial properties. The article also outlines the approaches to nanodentistry-bottom-up and top-down—and discusses how they influence the development of dental products. Despite the promising potential, challenges such as safety concerns, environmental impact, high production costs, and the need for regulatory oversight remain significant barriers to widespread adoption. The article concludes by emphasizing the pivotal role of nanotechnology in the future of Prosthodontics and highlights its potential to revolutionize oral healthcare through innovative, durable, and patient-centered dental solutions.

Key-words: Nanotechnology, Nanodentistry, Nanomaterials.

Introduction:

Nanotechnology is a branch of science and technology that deals with the development and utilization of materials or devices at the scale of nanometers. The word *'nano'* is derived from a Greek term meaning *"dwarf."* The concept of nanotechnology was introduced by Professor K. Eric Drexler, who stressed the significance of nanoscale processes in advancing technology.[1] Nanotechnology has emerged as a rapidly advancing discipline with wide-ranging applications across multiple scientific fields. Dentistry, including the specialty of Prosthodontics, is no exception to this trend. The application of nanotechnology in dental sciences has demonstrated significant potential in modifying and improving the mechanical and physical properties of various dental materials. In Prosthodontics, the incorporation of nanomaterials and nanoscale structures has contributed to notable advancements in mechanical strength, aesthetic outcomes, and biocompatibility of dental prostheses. This evolving domain represents a comprehensive framework for the utilization of nanoparticles in prosthodontic materials and procedures. Notably, nanotechnology has shown promising implications in the development and enhancement of acrylic resins, tissue conditioners, dental adhesives, composites, cements, porcelains, implants, and maxillofacial prostheses.[2] With ongoing advancements in research, nanodentistry presents considerable potential to transform oral health care practices. The unique capabilities of nanotechnology offer the prospect of developing innovative materials and techniques that can define a new era in dental treatment. However, for nanotechnology to be successfully integrated into mainstream dental care, it is essential to address key challenges, including public perception, safety concerns, and the establishment of appropriate legal and regulatory frameworks.[3,4,5]. The utilization of nanomaterials offers the potential to significantly enhance precision, durability, and functionality in dental restorations, thereby elevating the overall quality of patient care. This paper provides a comprehensive overview of nanomaterials and explores the diverse applications of nanotechnology within the domain of prosthodontics.

Access this article online	
Website: www.ujds.in	Quick Response Code
DOI: https://doi.org/10.21276/ujds.2025.v11.i2.16	

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Received : 6 June, 2025, **Published :** 30 June, 2025

How to cite this article: Amrita Jayaswal, Arvind Kumar Singh, Shruti Sharma Grover, & Shalini Pandey. (2025). Nanotechnology in Prosthodontics. UNIVERSITY JOURNAL OF DENTAL SCIENCES, 11(2).

Classification of nano-materials [6-11]

The general classification of nano-materials based on the nature.

1. Organic Nano-Materials

Polymer based nano-materials:

These materials are biocompatible and typically exhibit nanosphere or nanocapsule morphologies, which allow for easy activation and functionalization.

Lipid-based nano-materials: These nanomaterials typically range in size from 10 to 1000 nanometers and are widely utilized in biomedical applications. They possess a solid core composed of lipophilic molecules, surrounded by surfactant layers on their exterior surface.

2. Inorganic Nano-Materials

Metal: They are derived from precursors of metal.

Metal oxide nano-materials: Metal oxide nano-materials are synthesized because of higher reactivity and effectiveness like Cerium Oxide (CeO_2), Zinc Oxide (ZnO), Aluminium Oxide (Al_2O_3), Titanium Oxide (TiO_2), Magnetite (Fe_3O_4), Iron Oxide (Fe_2O_3).

Ceramic nano-materials: These materials are inorganic and non-metallic in nature, produced through controlled heating and cooling processes, and they find extensive applications in prosthodontic dentistry.

Semiconductor nano-materials: Their properties are in between metals and non-metals. They are widely used in electronic devices.

3. Carbon Based Nano-Materials:

They are carbon nano tubes, nanofibers and nanocarbon blocks.

Approaches to Nanodentistry [12]

Bottom-up approaches

This method involves bringing together smaller nanoparticles to create more complex assemblies with enhanced functional properties. The goal is to engineer tailor-made nanoscale particles capable of self-assembly or self-organization into larger, more intricate mesoscale or macroscale structures. An example of this is the synthetic creation and replication of DNA, achieved by pairing nucleic acids at the nanoscale level.

Top-down approaches:

In simple terms, this means breaking down complex structures into tiny nano-sized particles that have better functional properties. When the size of particles in a system becomes smaller, their surface area increases significantly. This leads to noticeable changes in physical properties due to both statistical and quantum mechanical effects.

The commonly used approach in dental material manufacturing is top-down approach. [13]

Nanodentistry products manufactured using top-down approach are: Nanocomposites ,nano light-curing glass ionomer restorative materials , nano impression materials, nano composite denture teeth , nano engineered acrylic resin, nanosolutions, prosthetic implants and bone graft materials.

Role of Nanoparticles In Prosthodontics

Acrylic resin:

Polymethyl methacrylate (PMMA) is being developed with the incorporation of titanium dioxide and iron oxide (Fe_2O_3) nanoparticles as pigments to closely mimic the natural hue of gingival tissue, thereby enhancing esthetics. This nanoparticle-infused PMMA exhibits lower porosity, increased molecular weight, and improved resistance to microbial and fungal adhesion. The integration of nanotechnology in PMMA not only boosts its biocompatibility but also enhances its mechanical properties, making it a more effective material for prosthodontic applications. [14]

Impression materials:

Nanofillers can be integrated into polyvinylsiloxane materials to enhance their hydrophilicity, resulting in fewer marginal voids. This modification also improves the material's flow characteristics and model pourability, ultimately leading to greater precision in detail reproduction. [15]

Tissue conditioner:

Tissue conditioner-lined prostheses can be cleaned using both chemical and mechanical methods; however, these cleaning approaches may potentially compromise the integrity of the relining material. To address this issue, studies in the literature have highlighted the antimicrobial effectiveness of silver nanoparticles. Incorporating silver nanoparticles into tissue conditioners offers a promising solution by enhancing antimicrobial properties without causing damage to the prosthesis.[16].

Denture teeth:

Denture teeth enhanced with nanotechnology are composed of polymethyl methacrylate (PMMA) combined with uniformly dispersed nano-sized filler particles. This composition offers several advantages, including high polishability, excellent stain resistance, improved surface hardness, enhanced wear resistance, and superior esthetics.[14]

Coating Agents in Prosthodontics:

Light-cured coating agents containing nanosized fillers are applied as a final layer over composite restorations, glass ionomer restorations, jacket crowns, veneers, and provisional restorations. These nano-filled coatings offer enhanced wear resistance, effectively minimizing abrasion and discoloration over time.[17]

Nanoceramics:

Nanoceramics are ceramic materials characterized by microstructural features at the nanoscale. Unlike conventional ceramics, nanoceramics exhibit exceptional properties, including improved toughness and ductility. One of their notable characteristics is superplasticity—despite ceramics being inherently brittle, nanoceramics demonstrate enhanced flexibility and toughness. Additionally, nanoceramics offer significantly superior mechanical properties, with strength and hardness levels often four to five times greater than those of traditional ceramic materials.[18]

Nanotechnology in Implants:

The application of nanotechnology in dental implants involves coating implant surfaces with nanoparticles. Research has shown that various cell types exhibit favorable responses to nanoscale surface topography. Since the implant surface directly interacts with surrounding tissues, it plays a vital role in determining both biocompatibility and biointegration. Key surface characteristics-including composition, energy, roughness, and topography-significantly influence the biological events at the bone=implant interface. The next advancement in this field may involve the development of biomimetic implants. Coatings using nano-textured titanium, hydroxyapatite, and pharmacological agents like bisphosphonates can stimulate cell differentiation and proliferation, enhance vascularization in cortical bone, and support both early and long-term bone remodeling. These nanoscale modifications also impact protein interactions, with studies indicating increased vitronectin adsorption on nanostructured surfaces compared to conventional ones. This, in turn, leads to improved osteoblast adhesion relative to other cell types, such as fibroblasts, promoting better osseointegration.[19]

Bone Replacement Materials:

Bone is a natural nanocomposite primarily composed of nanohydroxyapatite (HA) reinforced by collagen fibrils. The interaction between these components plays a crucial role in determining bone's mechanical strength and toughness. The fibrous collagen matrix transfers mechanical loads to the apatite crystals, providing resistance to fractures and contributing to the bone's overall toughness. Meanwhile, apatite deposited between collagen fibrils enhances the mechanical stability of the collagen network. Additionally, trace elements present in bone are essential for its growth and mineralization. Bone tissue exhibits properties such as osteoinductivity, a non-sintered and highly porous nanostructure, and the ability to undergo natural degradation through osteoclastic activity. Various hydroxyapatite (HA) nanoparticles commonly used in the repair of bone defects include formulations such as Ostim® HA and VITOSS® HA.[19]

Maxillofacial Prosthesis:

The incorporation of silver nanoparticles into maxillofacial prostheses has been shown to effectively prevent the growth of *Candida albicans* without causing any toxic effects to human dermal fibroblast cells. Additionally, titanium dioxide (TiO_2) and ceramic dioxide are noted for exhibiting minimal color changes over time. A study by Han Y in 2010 found that titanium oxide particles best preserve the optimal properties of maxillofacial silicone when mixed with the medical-grade 2186 maxillofacial silicone material.[20]

Challenges Faced By Nanotechnology:

While nanotechnology holds great promise in the field of dentistry, there are still several significant challenges that must be addressed before it can be fully realized. One key issue is the need to regulate and standardize the characterization, safety, and environmental impact of nanomaterials.[21] Currently, nanoparticles are not subject to specific regulations concerning their production, handling, and labeling.

Nanomaterials released into the environment can be modified by factors such as temperature and pH, potentially impacting soil and water and posing risks to plant and animal life. Additionally, once nanoparticles enter the human body, they may cross the blood-brain barrier. Given the unknown long-term effects of nanotechnology, potential hazards may not manifest for many years.

The fabrication and delivery of nanoparticles is a costly process that currently faces limited funding. Furthermore, the biocompatibility of nanomaterials has yet to be fully established, and social concerns, including public acceptance, ethics, and human safety, require further consideration. Challenges such as the precision positioning and manufacturing of nanoscale components, the development of cost-effective mass production techniques for nanorobots, and insufficient integration of clinical research also need to be addressed.[1]

Conclusion:

In dentistry, nanotechnology is increasingly being utilized to develop new materials that offer enhanced applications and benefits over traditional materials. This technology improves the quality of dental biomaterials, resulting in materials with superior properties. It provides valuable features for more accurate diagnoses, optimized treatment plans, and enhanced oral health care. Due to their exceptional physical, mechanical, chemical, and biological properties, nanomaterials have recently become highly regarded in various areas of dentistry, particularly in prosthetic treatments.[22]

The future advancement of prosthodontics technology is closely linked to the evolution of materials science. Nanomaterials have played a crucial role in driving both scientific innovation and clinical advancements in prosthodontics. The use of nanometals, nanoceramics, nanoresins, and other nanomaterials has significantly enhanced key properties such as elasticity modulus, surface hardness, polymerization shrinkage, and filler loading in prosthodontic materials. By reducing particle sizes from microns to nanoscale, nanotechnology improves the performance of these materials, with composites also benefiting from the addition of appropriate nanomaterials.[18]

In conclusion, the integration of nanotechnology into prosthodontics marks a major advancement in enhancing the quality and functionality of dental prostheses. By utilizing the unique properties of nanomaterials, such as improved strength, biocompatibility, and durability, prosthodontic treatments can offer patients more effective, long-lasting, and aesthetically pleasing results. As research progresses, the potential for nanotechnology to transform prosthodontics remains vast, with the promise of not only advancing material science but also improving patient care and clinical outcomes. However, challenges related to safety, cost, and long-term performance must still be addressed. With continued innovation, nanotechnology has the potential to redefine the future of prosthodontic practice, paving the way for more personalized and cutting-edge dental solutions.

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