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Nanotechnology In Prosthodontics

Dr. Sri Santhoshini. M, Dr. Seyed Asharaf Ali, Dr. Suma Karthigeyan,
Dr. N. Mahendira Kumar
Department Of Prosthodontics, Government Dental College And Hospital, Cuddalore, Chidambaram, India

Abstract
Nanotechnology is rapidly transforming the field of medicine, offering new and innovative solutions to some of the most complex challenges in healthcare. At its core, nanotechnology involves manipulating and engineering materials at the nanometer scale, where unique physical, chemical, and biological properties emerge. In medicine, this ability to work at such a small scale opens the door to revolutionary advancements, such as targeted drug delivery systems, improved diagnostic tools, regenerative medicine, and even nanoscale surgery.
Nanotechnology in prosthodontics represents a transformative approach to dental restoration and rehabilitation, enhancing the precision and effectiveness. Commonly used dental materials, despite their limitations in physical and biological properties, have not been replaced but can instead be enhanced with nanomaterials to improve their inherent qualities while remaining cost-effective. The current article focuses on the nanomaterials utilized in prosthodontics

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I. Introduction

Nanotechnology was discovered by the American physicist and Nobel laureate Dr. Richard Phillips Feynman who presented a paper called

There's Plenty of Room at the Bottom in December 29, 1959 at the annual meeting of the American Physical Society meeting at California Institute of Technology. Feynman talked about the storage of information on a very small scale. However, it was Norio Taniguchi, Japanese scientist who used the term nanotechnology in his paper published in the year 1974 as "nanotechnology mainly consists of the processing of separation, consolidation, and deformation of materials by one atom or one molecule". In 1986, K. Eric Drexler published the first book on nanotechnology "Engines of Creation: The Coming Era of Nanotechnology". It was introduced into dentistry first as nanocomposites in the year 2002 by Filtek Supreme.

Nano comes from Greek word "nannos" meaning 'dwarf'. The structures range in the physical size of 1-100 nanometers (nm). nanometre means one millionth of a meter (10^{-9}). Nanotechnology is used in various fields such as electronics, aerospace as well as medicine.

Nano dentistry is still considered as an emerging field with a huge potential to yield new innovative generation of technologically advanced biomaterials in prosthodontics, orthodontics, periodontics, operatives, or restorative dental sciences. It is expected that nano dentistry will eventually give rise to highly efficient, effective, and personalized dental treatment. Nano biomaterials may be in the form of nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerens, nanospheres, nanocapsules and others.

II. Approaches For Nanomaterial Manufactering

The manufacturing approaches of nanomaterials fall under 4 categories:
1. Top-down approach
2. Bottom-up approach
3. Functional approach
4. Biomimetic approach

Top-Down Approach:

The top-down approach is the breaking down of bulk material to get nano-sized particle. Top-down approach is the most conventional practice for manufacturing nanomaterials. This can be achieved by using techniques such as precision engineering and lithography, mechanical milling, etching, laser ablation, sputtering, electro – explosion.

The materials formed with top-down approach are used in the manufacturing of Nano anaesthesia, cancer diagnosis, hypersensitivity cure, oral health care etc.

Bottom-Up Approach:

The bottom-up approach refers to the building up of nanostructures from atom or molecular level. This practise is the most commonly used method for manufacturing nanoparticles. This approach involves using controlled manipulation of self-assembly of atoms and molecules which are in the range of 1nm to 100nm. The methods used to obtain nanoparticles are supercritical fluid synthesis, spinning, sol-gel process, laser pyrolysis, chemical vapour deposition, molecular condensation, chemical reduction, green synthesis. The materials formed with the bottom-up approach are Nanocomposites, nanoencapsulation, prosthetic implant, bone replacement material, nanoneedle etc. (micellar arrangement, polymerization, crystallization, precipitation)

Functional Approach:

Functional approach values on the production of nanoparticles with a specific function.
The materials formed with this approach are antimicrobial medicines, nutrient supplements, etc.
Targeting root issues rather than symptoms.

Biomimetic Approach:

Creating new material by mimicking natural processes and natural matters.
Still a futuristic approach. (biognosis or biomimicry)

III. Nanomaterials In Prosthodontics

Impression Materials

Nanofillers are added to impression materials such as vinylpolysiloxanes which improve the hydrophilicity of the material which in turn improves the flow and increases precision.

Nanomaterials used in irreversible hydrocolloid impression material acts as disinfectants, hence called "self-disinfectant materials".

Silver nanoparticles (AgNPs) of about 9 and 14 nm exhibited superior antimicrobial activity against gram-positive and gram-negative bacteria. AgNPs of 5–20 nm also showed inhibition of HIV-1 virus replication. These investigations suggest that use of finer size AgNPs can significantly enhance their antimicrobial activity. Finer particle size exhibit antimicrobial property because of the higher surface area which can interact with the microoraganisms.

Ginjupalli et al concluded that the incorporation of silver nano particles to irreversible hydrocolloid impression had significant antimicrobial action and also concluded that the change in properties of AgNPs incorporated irreversible hydrocolloid can be considered clinically negligible.

Dental Ceramics

Although ceramics are widely used for their excellent plasticity and mechanical properties, their primary drawback is their susceptibility to cracking. Nanomaterials are incorporated in ceramics to improve this drawback. "Nanoceramic" refers to "the ceramic material with nanoscale
dimensions in the microstructures phase".

Tokushi et al.,(2012) evaluated the addition of nanoparticles of precious metals of silver and platinum to increase the fracture resistance of porcelain. They found that the addition of silver and platinum nanoparticles improved the Young's modulus and the fracture toughness of commercial porcelain.

Mitsunori et al., (2013) investigated the toughening of porcelain through the addition of silver nanoparticles. The concentration of silver in the solution was adjusted to 100, 200, 500, and 1000 ppm (Ag100, Ag200, Ag500, and Ag1000). The results showed that the addition of silver nanoparticles significantly increased the fracture toughness and Vickers hardness of the porcelain. However, the addition of Ag500 and Ag1000 nanoparticles led to a colour change.

According to Cherif A Mohsen, et al, The addition of silver nanoparticles increased the fracture strength of dental ceramic and addition of silver hydroxyapatite nanoparticles has decreased the fracture strength of dental ceramic and both affected the colour of dental ceramic adversely.

Acrylic Resin

Acrylic resin is widely used in the fabrication of temporary prosthetic base materials, provisional prosthesis, dentures. Polymethyl methacrylate has advantages such as high hardness, rigidity, discontinuity deformation, absence of taste, odour, tissue irritation, toxicity, insolubility in body fluids and easy processing characteristics. However, its main disadvantages are the instability of colour, poor resistance to wear and tear, volume shrinkage after polymerization, staining and discoloration easily, slow abrasion resistance and high microbial adhesion, compromised flexural strength, and less fracture and impact strength. Hence to overcome these drawbacks, nano particles have been added to the PMMA to improve the mechanical properties.

Various nanoparticles which are added are silver (Ag), modified silver such as silver + amorphous calcium phosphate (Ag + ACP), silver vanadate ($AgVO_3$), silver-titanium dioxide ($Ag–TiO_2$), silver-sulfadiazine-mesoporous silica (AgSD-MS), and graphene-silver (G-Ag); titanium dioxide (TiO_2); silicon dioxide (SiO_2); ACP; calcium fluoride (CaF_2); quaternary ammonium methacrylate–modified silica (QMS); copper iodide (CuI); modified ZnO such as silanized ZnO (SiZnO) and nonsilanized zinc oxide (NosiZnO); graphene oxide; diamond (D); ceria (Ce); chitosan (Cs); and gold (Au)

Silver Based Nanoparticles:

The action of silver nanoparticles is because of the release of bioactive silver ions(Ag^+) which react with bacterial cell membranes. The large surface area of silver nanoparticles allows a larger number of atoms to interact with their surroundings. The positive charge of the metal ion (silver nanoparticle) reacts with the negative charge of the bacterial cell membrane and inhibit respiratory enzymes and causing cell membrane damage. Hence, addition of silver nanoparticles in denture is beneficial for immune-compromised and geriatric patients.

Titania (Tio_2) Based Nanoparticles:

Titanium dioxide nanoparticles (TiO2NPs) create strong antimicrobial activity through photocatalysis. When added to PMMA they have superior mechanical properties such as increased modulus of elasticity around 230 GPa, antimicrobial activity, biocompatiblity, white color, chemically stable, corrosion resistant and economical. Also silanized TiO2 NPs in PMMA improved the impact strength, transverse strength, and surface hardness of the resin and decreased its water sorption and solubility.

Silica (Sio2) Based Nano Particles:

The incorporation of mesoporous silica nanoparticles loaded with an antifungal drug (amphotericin B) resulted in long-term antifungal activity against Candida albicans.

Zirconia:

ZrO2 nanoparticles (NPs) added to the PMMA improved the thermal conductivity, biocompatibility, impact strength, flexural strength, compressive strength, fatigue strength.

Silanized zirconia NPs with PMMA, resulted in higher flexural strength and impact strength of acrylic resin, but with no improvement in tensile strength

Nanodiamond (Nd):

Adding ND nanoclusters (20nm; ~0.83 wt%) to PMMA significantly improved the elastic modulus (~2.084GPa) and impact strength.

Adding only 0.1 wt.% ND to PMMA remarkably increased the flexural strength and inhibits the growth of candida albicans

Silanized Al2o3 Np: improved the thermal properties (decreased the coefficient of thermal expansion and contraction) and the flexural strength of acrylic resin, decreased water sorption and solubility.

Hydroxyapatite (Ha) Np: increases both the fatigue and compressive strength.

The addition of GOLD NP significantly improved the flexural strength and thermal conductivity to almost double the value of pure PMMA.

The addition of platinum (Pt) NP increased the bending deflection of PMMA and palladium improved flexural strength compared to silver and gold, which showed the lowest flexural strength value.

Denture Liners

Silver-doped bioactive glass nanoparticles have been added to denture soft liners for sustained release of Ag + ions. Although these nanoparticles demonstrate antimicrobial activities against C. albicans, S. aureus and S. mutans; antimicrobial activity is lost after they are incorporated into the soft liner.

Zeolites are porous, inorganic aluminosilicate crystallite structures that may be doped with antimicrobial cations such as silver, via replacement of the alkaline or alkaline earth metal ions by an ion-exchange process. This type of silver zeolite added to denture liner are effective against C. albicans as well as gram positive and gram-negative bacteria.

chitosan or chitosan quaternized with 2- [(acryloyloxy)ethyl] trimethyl ammonium chloride have been used to modify denture soft liners. No colonies of C.albicans were found in the modified soft liners.

Polycationic crosslinked Quaternary ammonium polyethylenimine nanoparticles (QAPEI) antimicrobial nanoparticles have also been incorporated into soft liners of removable obturator prostheses in immunocompromised, post-surgical head and neck cancer patients to prevent the colonization of C. albicans.

Nanoparticles In Adhesive Dentistry

In a study done by welch et al the addition of tio2 to adhesive interfered with the bacterial activity and also had a positive effect on tooth remineralization in simulated body fluid.

The concept of self-healing adhesives presents an intriguing advancement in adhesive dentistry. The self-healing polymer relies on encapsulation of monomers and catalyst and reinforcing these encapsulated healing precursors into polymer. As the cracks are triggered, these capsules rupture and healing monomers fill the crack. This allows the healing of crack site. Ouyang and co-workers reported the use of triethylene glycol dimethacrylate (TEGDMA) incorporated in the polyurethane nano capsule. This nanoencapsulated monomers in dental adhesives increase the bond strength and also improve bond strength between resin and tooth surface.

Dental Implants

Modifying the implant surface from the macroscale to the nanoscale enhances the healing process of the implant. The nanostructured dental implants have better attachment, spreading and differentiation with peptides, stem cells and pre osteoblasts. Techniques for surface modification are direct surface tailoring (e.g. Etching, sandblasting) and or functionalization (bio glass coatings or polymers, peptides etc.). however, these surface modifications damage screw threads by decreasing surface hardness and by loss of superficial material layer.

Nowadays, surface etching with solutions of alkaline potassium, alkaline sodium or hydrogen peroxide forms stable oxide layers forming nanostructures such as nanotubes, nanoneedles, nanowires. Nanofeatures increase surface wettability and also accelerates healing process.

Nanostructured ceramics provide closer contact with surrounding tissues and reduce inflammatory process. For antibacterial property, various metallic NPs or their combinations with antibiotics are used.

IV. Conclusion

Nanotechnology enhances material properties such as modulus of elasticity, surface hardness, polymerization shrinkage, filler loading and antimicrobial activity, which in turn leads to improved patient care. Further research on nanoparticles is essential for their future applications. While the use of nanoparticles offers numerous advantages, it's important to remain mindful of potential challenges, such as cytotoxicity and oxidative stress to tissues, to ensure safe and effective applications.

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