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Nanomaterials in Prosthodontics

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ABSTRACT
Nanotechnology is the science involving minute particles that include particles smaller than micron-size to nano-size (10^{-9}), which cannot be seen in normal vision. Nanotechnology deals with the concept of creating materials or functional structures by controlling atoms and molecules. The material used in nanotechnology is called nanomaterials. The use of nanotechnology in the field of dentistry is called Nano-dentistry where the chemical, physical and biological aspects of nanostructures are considered in dental materials. Nanostructures are formed from various atoms and molecules. Nanomaterials are used in diagnostics in dentistry, and also used in delivering oral drugs and fluids that prevent and cure oral diseases like oral cancer. The nanotechnology field has emerged due to its assorted dental applications of nanotechnology. When nanoparticles were added to dental materials like composites, metals, ceramics, resin, or other matrix materials which are widely used due to their properties such as Modulus of elasticity, Surface hardness, Polymerization shrinkage, and Filler loading, these properties were increased significantly by nanoparticles. This article discusses the application of nanomaterials like nanometals, nanoceramics, nano-resins, nanocomposites, and many more in prosthodontics.
Keywords: *Nanodentistry, Nanocomposites, Nanomaterials, Nanotechnology, Prosthodontics.*

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INTRODUCTION

Nano-technology is a combination of structures and functioning materials in extremely small sizes where different physical and chemical methods are utilized. The size of the particle may range between 1-100nm (nanometre) is used. Such particles are called Nanoparticles. Nanotechnology has three requirements, technology that is developed at the atomic level, molecular level, or macro-level having 1-100nm size, which generates and uses structures, devices, and systems having novel properties and functions as a result of their small or minute size and their ability to manipulate the atomic or molecular size[1-5].
For a few years, inorganic nanoparticles where structures show substantially unreactive and has good properties, phenomenon, and functions because of their small sizes, this has raised much interest, especially regarding their use in biological and pharmaceutical applications. Recently it has been shown that specially made metal oxide nanoparticles acquire good mechanical strength as well as good antimicrobial activity. While in inorganic substances antimicrobial agent is silver which has been used from ancient times to treat infections, and it also controls spoilage. The word Nanotechnology was first used in 1977 by Professor KE Drexler. The development of "Nanodentistry" will help achieve better oral health with the help of nanomaterials that consists of tissue engineering as well as nanorobotics [6].
Numerous treatment methods are described in the literature, like remineralization of the damaged tooth, treating tooth hypersensitivity, helpful orthodontic nanorobots, used in dental cosmetics, modified local anesthesia, photosensitizer carriers, improvised impression materials, nanoencapsulation, new nanoneedles, highly active bone replacement materials with the generations of biomaterials[7]. Nanorobots have the ability to swim hence making them able to reach surfaces that toothbrush bristles and dental floss cannot reach. Further, nanorobotsare converted into dietary fibers in the oral cavity after their work is done. These are also used in the field of gerontology, pharmaceutical research, and clinical diagnosis. Coming to the field of Implantology, nanomaterials have shown regenerative effects for hard and soft tissues present around the implant site. The ability to produce new tissue tends to replace the implanted biodegradable materials which throw light on newer aspects of tissue regeneration. In prosthodontic dentistry, nanomaterials are being added to ceramics and porcelains, restorative metals, acrylic resins, composites, to dental adhesive systems, to dental cement, and to implants, and also added

in maxillofacial prosthesis as changing these materials to smaller sizes has increased their strength, durability, and efficacy[8].

NANOTECHNOLOGY IN BRIEF

Nano-technology is defined as the composition of materials and functional systems at the minute molecular size, the real meaning of nanotechnology is described as the ability to produce materials using newer technologies and tools that are of very high quality. Sizes as small as 1mm, the normal scale of nanoparticles is 1-100nm hence the devices are fabricated in that size range.

Nanotechnology has primarily changed healthcare in various ways:

- They are used in new diagnostic and preventive procedures.
- It is used to customize the treatment plan according to the patient's profile.
- Also used in drug delivery systems and in gene therapies.

Nanotechnology is a field that is thought to be an extension of existing sciences on small scale, or it can be the revolution of existing sciences with recent terms.

Modes of nanotechnology

Nanotechnology has three molecular technologies that also have mutual overlaps and are systematically more powerful. Small-sized structure materials and devices are made for most advanced diagnostics in addition to biosensors, targeted drug delivery systems, and smart drugs are also produced. Molecular medicine is formed via genomics, proteomics, and artificial biorobots (microbial robots).Molecular machines and medical nanorobots lead to rapid pathogen diagnosis and eradication and proper proliferation and increased natural physiologic functions.

Approaches in nanotechnology

Types of approaches applied in the formation of nano-sized particles are:

- Bottoms-up technique
- Top-down technique
- Functional technique

The last technique which is the functional technique tends to not follow the production method of nano-sized particles with a goal to produce a nanoparticle with specific functionality.

Bottom-up method

In this method arranges small components into more complex groupings. Procedures that use this technique are local anesthesia, Hypersensitivity curing procedures, Nanorobotic dentifrice, Nano toothpaste, cosmetic procedures, orthodontic procedures, photosensitizers along with their carriers, diagnosing of oral cancer, entire tooth replacement procedures, tooth renaturalization methods, procedures for treating cancer in the oral cavity, biomimetics processes for dental, regeneration methods mostly endodontically, and Nanoterminators[9].

Top-down technique

This approach produces smaller devices by using larger ones to direct their groupings so small features are made with bigger materials patterning them to make a small size structure in an accurate pattern. Complex structures have a lot of properly placed nanostructures that can be manufactured. Materials are shrunk to minute size which shows new properties instantly making them stand out for various new applications.

If the size of the system reduces then there is a raise in the ratio of surface area to volume including various physical phenomena is marked. This method likes to form smaller devices using larger ones to direct their grouping. It includes Pit-fissure sealants, Bone targeting Nanocarriers, etc. The methods used are Nanocomposites, Nano Light-Curing Glass Ionomer Restorative material, Nano Impression Materials, Nano-Composite Denture Teeth material, Nanoencapsulation, Plasma Laser application methods, Prosthetic Implants-modified, Nano needles, Bone replacement materials, and Nanoparticle made disinfection in endodontics[10].In the functional approach method components of required functionality are formed without any regard to how they might be grouped. Other approaches that are used at Rice University are given as follows:

Wet nano-technology: This analyses the system biologically which mostly exists inside water-rich environment and contains genetically linked materials, membranes, enzymes used, and minuscule cell parts.

Dry nano-technology: This method is taken from surface science and physical chemistry and it focuses on the production of materials in carbon, silicon, and organic substances.

Computational nano-technology: This method allows modeling and simulation of difficult small-scale structures. Computation technology is very important to get through in nanotechnology [11].

Application of nanotechnology in general:

- In pharmaceuticals- nanotechnology applications involve Cancer, Antivirals, Arteriosclerosis, some lung diseases, diabetes, Gene therapy, Tissue engineering, and cell repair.
- In nanodevices- contains delivery of diagnostic and therapeutic means. It is classified into three important molecular machinery.
- In nano-materials and devices are used in advanced diagnostics aids and biosensors, targeted drug delivery systems, and in smart drugs.
- Microbial robots are used in molecular medicine, genomics, proteomics, artificial probiotics, etc. thus they indirectly enhance physiological functions

NANOPARTICLES IN PROSTHODONTICS

Acrylic resin

Acrylic resin's importance in dentistry is evident. They are used in temporary prosthetic base materials, provisional prostheses, dentures, and orthodontic removable appliances like retainers and functional appliances. These resins commonly contain methacrylate's, especially poly methyl methacrylate (PMMA), and additional copolymers[12].One of the major problems that are commonly faced while using removable acrylic appliances is they are conducive to plaque accumulation due to surface porosity and food retentive configuration, which also increases the rate of bacterial activity of cariogenic oral flora[13] Titanium dioxide nanoparticles are added to biomaterials to promote antimicrobial properties[14-15] Antimicrobial activities of titanium dioxide against *Candida Albicans*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, lactobacillus acidophilus, etc. are confirmed in recent studies[16-19]. Along with the major catalytic effect, other characteristics like white color, low toxicity, high stability, and efficiency and availability [20-21] makes titanium dioxide an appropriate antimicrobial addition in acrylic resin. In compounds such as inorganic carriers like apatite, zeolite, and phosphate, Silica dioxide is promising because of its porous structure and adsorption properties. Nanoparticles of silica dioxide have extremely high surface activity and adsorb various ions and molecules [22]. Silver nanoparticles for their small size have better dispersion in the PMMA matrix and form a larger area for oxidation [23]. Release of silver ions is very essential in the antibacterial mechanism of silver nanoparticles by rupturing the cell wall that causes protein denaturation, blocks cell respiration, and lastly causes microbial death [24].

Tissue conditioner:

They are used to fasten the healing of denture-bearing tissues having trauma, damage, or residual ridge resorption due to ill-fitting dentures. Dentures with conditioners are kept clean by mechanical and chemical ways but this can cause some damage to tissue conditioners [25-26]. Silver is known for its antimicrobial feature. To overcome this problem silver nanoparticles are added to tissue conditioners for their smaller size as they provide a large surface area [27].

Dental adhesives: -

These are materials used for adhesion and cohesion among two different kinds of materials or between a material and a natural tooth structure. Polymerizable silane is added to adhesives to raise the cohesive strength. As the adhesive liquid is not viscous, the filler particles settle down during storage which causes inconsistency in their performance. This disadvantage is overcome with discrete silane-treated nanoparticles of silica or zirconia in the size range of 5-7nm added to dental adhesives [28]. Based on a study by Silikas *et al.* there is no reduction in bond strength of adhesives after the addition of silica or zirconia nanoparticles obtained [29].

Composites

Composite resins are synthetic resins used in dentistry for restoration. Synthetic resins are used as restorative materials because they are insoluble, aesthetic, insensitive to dehydration, easy to manipulate, and reasonably inexpensive. Nanofillersare dental composites where fillers are in the 1-100 nm range. Two types of nanoparticles are used in the nanofiller dental composite [30]. The first type is nanometric particles which are essentially mono-dispersed non-aggregated and non-agglomerated particles of silica. The second type is nanoclusters used in order to overcome the disadvantages of the previously used nanomeric nanoparticle. Nanoclusters are made by lightly sintering nanomeric oxides to form clusters of controlled particle size distribution. Nanoclusters are synthesized from silica *and* from mixed oxides of silica and zirconia [31-33]. In nanohybridcomposites, Prepolymerized organic fillers are added to improve the undesirable properties of composites where nanomers are included. Titanium dioxide reinforced with resin-based composites. In a study done by Xia et al. titanium dioxide nanoparticles added with organosilaneallyltriethoxysilane (ATES) are used to increase the microhardness and flexural strength of resin-based composite [34]. Study in which titanium dioxide nanoparticles are synthesized in an aqueous solution is dispersed into an epoxy polymer matrix. The resulting material has better mechanical properties. Based on a study by Al haik *et al* [35] nanocomposite with alumina nanoparticles raises the hardness of the nanocomposite compared to other nanocomposites. The formation of alumina nanoparticles is done by a low-power plasma torch[36].A study by ZhanhuGuo *et al*, reported that alumina nanoparticles are successfully functionalized with a bi-functional silane surfactant in a facile method which caused significant raise in both modulus and strength. The inclusion of the functionalized nanoparticles had no deleterious effect on the thermal stability of the composite. While the addition of vinyl ester resin after curing effectively prevented alumina nanoparticles from getting dissolved in acidic and basic solutions [37].

Dental porcelain

Porcelains are used in ceramic restorations that are brittle and sometimes required to replace fractured or damaged restorations. Porcelain is the most fragile and shows elastic deformity instead of plastic deformation which causes damage to restorations. The inclusion of silver nanoparticles has mainly increased the fracture toughness and Vickers hardness of the porcelain. Tokushifujieda *et al*. did a study in which they included nanoparticles of precious metals like silver and platinum in dental porcelain and came to conclude that the addition of silver and platinum nanoparticles raised the mechanical properties of porcelain. It also increased both Young's modulus and the fracture toughness of the dental porcelain. It is seen that the silver nanoparticles raised the fracture toughness more than platinum nanoparticles [38].

Gingiva coloured hybrid nanocomposite:

It is mainly used to rectify cervical defects and exposed and discolored and hypersensitive parts of the tooth, preferably in the visible anterior region. The pink shade like gingiva allows the correct visualization of the gingival tissues. The system has6 different flowable restoratives in VITA G1, G2, G3, G4,GOL, and GOD shades along with 6 different fine hybrids having thicker consistency and gingiva shaded composite restoratives in VITAG1, G2, G3, G4, GOL, GOD Shades.

Dental implants:

Bis-GMA Urethane Di-methacrylate, Inorganic nanofillers, and Ytterbium Fluoride Implants are used in implants. Implant therapy is an important advancement in dentistry in the past few decades. Osseointegration is largely accepted in clinical dentistry as the ground for dental implant success. Failure to obtain osseointegration is because of one or more implant, local anatomic, local biologic, systemic, or functional reasons [39-40]. Nanostructured hydroxyapatite coatings for implants have received attention in the past few decades. It promotes bone formation around the implant and fastens osteoblastic activity like adhesion, proliferation, and mineralization. Nanoporous ceramic implant coatings need a different method to improve implant properties, i.e.,anodization of aluminum. This method was used to create a Nanoporous aluminum layer upon the surface of titanium alloy implants [41]. Nanoporous alumina has the potential of being rendered by loading the porous structure with appropriate bioactive agents which improves cell response and helps in Osseo-inductive activity [42]. Titanium and Titanium alloys are novel metals that are successfully used as dental implants because these materials have good integration with the nearby bone surface without forming any fibrous tissue interface. For controlling the increasing, bone growth, surface treatment is used such as surface roughening by sandblasting, hydroxyapatite coating [43] formations of titanium dioxide, or titania [44].

Nanosurface coating:

New coating procedures are formed for applying hydroxyapatite and related calcium phosphates (CaP), (the mineral of bone) coated onto the surface of implants. Studies show CaP coatings give titanium implants anosteoconductive surface[45-46] Following implantation, the dissolution of CaP coating occurs in the peri-implant region where raised ionic strength and saturation of blood cause precipitation of biological apatite nanocrystals upon the surface of implants. This biological apatite layer has proteins that cause the promotion of the adhesion of osteoprogenitor cells which will again produce the extracellular matrix of bone tissue. It is also seen that osteoclasts cells which cause bone resorption are able to degrade the CaP coatings in enzymatic ways and form resorption pits on the coated surface. Cap coatings on metals promote an early Osseointegration of implants through direct bone bonding when compared to non-coated surfaces. The problem is to create CaP coatings that would dissolve at the same rate to bone apposition to get direct bone contact on implant surfaces. Nano surface modifiers, Bone morphogenic proteins (BMP-2) raise osteoblastic proliferation and the included antibiotics causes supercharged bone growth.

Nanoscale surface modifications:

Surface properties play a major role in biological communications. The nano-sized roughness and surface chemistry have a greater role in the interactions among surfaces with proteins and cells. These early interactions will pave the way for late tissue integration. Different methods have been reported for increasing bone healing around metal implants [47-48]. Modifying surface roughness seems to enhance bone-to-implant contact and also improves clinical performance [49]. Grit blasting, anodization, acid etching, chemical grafting, and ionic implantation are the commonly used methods for changing the surface roughness of metal implants. A combination of these methods is used such as acid etching after grit-blasting to eliminate the contamination, by blasting residues on implant surfaces. This residue may hamper the osseointegration of the titanium dental implants[50-51] It is seen that grit-blasting with biphasic calcium phosphate (BCP) ceramic particles gives a high average surface roughness and particle-free surfaces after the acid etching of titanium implants. Studies conducted both in vitro and in vivo show that BCP grit-blasted surfaces initiate early osteoblast differentiation and bone apposition when compared to mirror-polished or alumina grit-blasted titanium [52-53]. Anodization is a technique used to obtain nanoscale oxides on metals which include s*titanium.* Adjusting the anodization norms such as voltage, time, and shaking, nanoscale properties can be controlled [54-55].

Bone replacement materials:

Bone is naturally a nanostructure composed of organic compounds (mainly collagen) added with inorganic ones i.e., Hydroxyapatite. The natural nanostructure is the feature aimed by nano-technology to exactly replicate orthopedic treatment and other dental treatment modalities [56-58]. With the raised particle size the surface area is also raised in volume. The nanocrystallites have an unsteady microstructure due to nanopores that are present between the crystals' structures. These structures have pores in the micro areas. This method ensures the creation of a rough surface is created upon the limiting layer present in the middle of the biomaterial and cell, essential for fastened growth of cells. The range of porosities present is around 60% and is there in both the nano-pores and the micro-pores. The pores are all interconnected with each other. As the cells are much bigger when compared to the small pores, the plasma of blood that has various essential proteins is collected in the interstitial spaces. The pore surface is changed such that it actually depends on the proteins. This occurs because of silica molecules. Silica plays a major role.

Tissue-integration:

The incidents that occur at the tissue-implant interface area are affected by the chemistry, the topography, and the wettability of the implant surfaces. The problem during producing an innovative implant surface is raising the success rate while reducing the healing time for tissues in immediately loaded implants, mainly including the look. The goal is to create implant surfaces that can be predictable, can be controlled, and can have guided healing of the tissue [59].

Effects of nano-particles:

Nanotoxicology deals with the side effects of designed Nanodevices and nano-sized structures in living beings. Literature shows a major connection between raised cardiovascular mortality, various other extrapulmonary effects, damaged tissues, and systemic side effects because of the increase in the rate of assimilation of non-biodegradable Nano-sized particles by the skin and the lungs. (Ag) nano-sized particles show raised harmful effects on the human health system and also on the environment. Long-term exposure to (Ag) can cause side effects like irreversible blue-grey skin discoloration and in the eyes, which also causes damage to the liver and kidney [60-61].

CONCLUSION

Numerous nano-sized particles are used in the production of acrylic resins, conditioners, adhesives, composites, restorative cement, porcelain, implant restorations, and maxillofacial reconstructive prosthesis are shortly explained. Research is needed in describing the cytotoxicity of many nanoparticles used, their accepted concentration, and structural stability for a safe as well as proper experience. Various suitable nanoparticle that is used along with various materials in prosthodontics- such as Silver (Ag) particles in acrylic resin, (Ag) particles in silver nanoparticles, silica or zirconia particles in dental adhesives, Titanium (Ti) dioxide particles in composites, (Ag) nanoparticles in dental cement, (Ag) and platinum (Pt) particles in porcelain, hydroxyapatite and Nanoporous alumina particles in implants, (Ag), (Ti) and cerium dioxide particles in the maxillofacial prosthesis.

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