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International Journal of Current Research
Vol. 12, Issue, 03, pp.10529-10533, March, 2020

DOI: https://doi.org/10.24941/ijcr.38113.03.2020

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

NANO TECHNOLOGY IN PROSTHODONTICS- AN OVERVIEW

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ARTICLE INFO

Article History:
Received 14th December, 2019
Received in revised form
10th January, 2020
Accepted 18th February, 2020
Published online 28th March, 2020

Key Words:
Nanotechnology,
Nanomaterials, Nanoparticles,
Nanodentistry.

ABSTRACT

Nanotechnology is extremely diverse and multidisciplinary field, ranging from novel extensions of conventional physics to completely new approaches based upon molecular self-assembly to developing new materials and machines with nanoscale dimensions. Nanotechnology is based on the perception of generating functional structures by monitoring atoms and molecules on a one-by-one basis. It deals with all physical, chemical, and biological properties of structures with their components at nanoscale magnitudes. It has been shown that the performances of many biomaterials used in prosthodontics have been significantly enhanced after their scales were reduced by nanotechnology, from micron-size into nanosize. Properties such as modulus elasticity, surface hardness, polymerization shrinkage and filler loading, were significantly increased after the addition of the nanomaterial.

Citation: ***Dr. Neethu Elizabeth Antony, Dr. Padmaja, S., Dr. Malathi Dayalan and Dr. Savitha, P.N.*** **2020.** "Nano technology in prosthodontics- an overview", *International Journal of Current Research*, 12, (03), 10529-10533.

INTRODUCTION

Nanotechnology is bringing a revolution in the world of science pertaining to the creation and use of materials or devices at nanometer scale. It works at the level of atoms and molecules and manipulates them according to the need. The word ''nano'' is derived from a Greek word ''nannos'' which means ''dwarf. ''In recent years, nanomaterials have captured more and more attention because of their unique structures and properties. Dental materials have evolved with the advent of nanotechnological research focusing on the production and application of nanoparticles with high-quality structural characteristics. The incorporation of a myriad of nanoparticles into dental materials (e.g., quartz, colloidal silica, zirconia, zinc oxide) represents an innovation by manufacturers to improve the chemical and physical properties of these materials (Aeran Himanshu, 2015). National Nanotechnology Initiative defined nanotechnology as the "Research and technology development at the atomic, molecular and macromolecular levels in the length scale of approximately 1-100 nm range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size (Gopinadh *et al*., 2015)".

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Need for nanotechnology: Materials reduced to the nanoscale can suddenly show very different properties enabling unique applications. It is this desirable alteration in the physicochemical properties of a bulk material when reduced to a nanoscale that highlights the importance of applied nanotechnology in various fields including dentistry (Gopinadh *et al*., 2015). Like other branches of dentistry, restorative dentistry including prosthodontics and implant dentistry has made remarkable progress with respect to nanotechnology. In prosthodontics, various types of nanomaterials are added to improve the properties of commonly used materials like resin denture base material, ceramics, polyvinyl siloxane impression material, maxillofacial materials, luting cements, etc. Research on addition of nanoparticles in this regard will promote the usage of such materials with greater efficiency and durability will definitely be of great advantage to dentists and patients undergoing prosthodontics treatment (Sabarigirinathan *et al*., 2015).

Concepts: Literature has given two concepts of nanotechnology, i.e., broad and narrow concepts. Broad concept signifies a technology smaller than microtechnology. Narrow concept programs and manipulates matter with molecular precision (Aeran Himanshu, 2015).

Manufacturing

There are two perspectives

- Building up particles by combining atomic elements.
- Using equipment to create mechanical nanoscale objects.

INDIVIDUAL ATOMS + MOLECULES = COMPLEX STRUCTURE (extraordinary properties).

A nanomanufacturing technology should be

- Capable of producing components with nanometer precision
- Able to create systems with components
- Able to produce many systems simultaneously
- Able to structure in three dimensions
- Cost effective (Jhaveri *et al*., 2005).

Approaches: Three approaches (Fig 1) have been followed in the production of nanoparticles, namely bottom up approach, top-down approach, and functional approach.

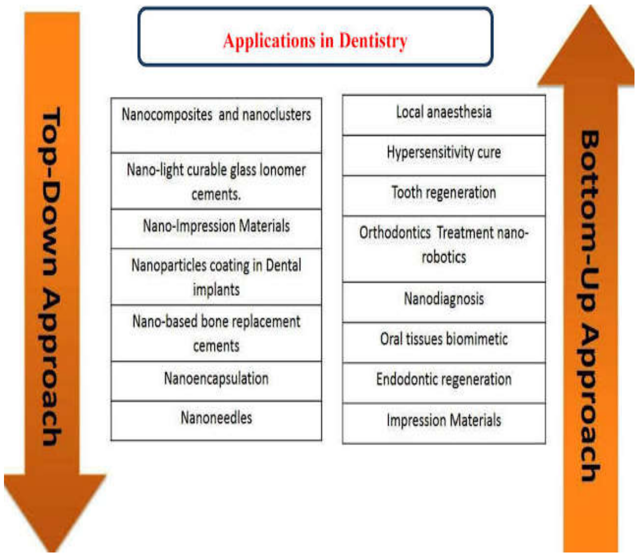

Fig. 1. Approaches of nanotechnology

The functional approach disregards the method of production of a nanoparticle, and the objective is to produce a nanoparticle with a specific functionality. i.e., does not give importance to the method of production of a nanoparticle; rather, it emphasizes on production of nanoparticle with a specific use. In top-down approach, particles are synthesized in the conventional manner and made smaller by grinding or milling. Top down fabrication reduces large pieces of materials all the way down to the nanoscale. This approach requires a large amount of materials and can lead to waste, if excess material is discarded. In the bottom-up approach, nanoparticles are synthesized by direct molecular synthesis and bonding, i.e., they are synthesized from molecular level. The bottom up approach to nanomanufacturing creates products by building them up from atomic and molecular scale components, which can be time consuming (Kumar Saravana, 2006).

Nanomaterials: The concept of "nanomaterials" formed in the early 1980s, referring to zero-dimensional, one-dimensional, two dimensional, and three-dimensional materials with a size of less than 100 nm.

Nanomaterials have small size, large surface area, high surface energy, a large proportion of surface atoms, and four unique properties:

- Small size effect
- Quantum size effect
- Quantum tunneling effect
- Surface effect.

Nanomaterials can be divided into four categories of nanopowder, nanofiber, nanomembrane, and nanoblock, in which development of nanopowder is longest, and its technology is most mature. Different types of nanoparticles include nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes (bucky-balls), nanospheres, nanowires, nanobelts, nanorings, nanocap, and many more.

Nanorods: Nanorods (Fig 2) are of particular interest in a restorative context. Since they are similar to the enamel rods that make up the basic crystalline structure of dental enamel, nanorods may contribute to a practical artificial approximation of such a naturally-occurring structure. Eg: zinc oxide nanorods, silica coated gold nanorods, aluminium nanorods.

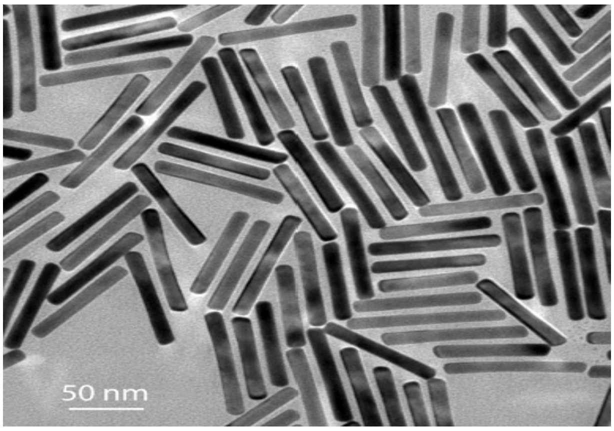

Fig 2. Nanorods

Nanotubes: Nanotubes (Fig 3) of various types have been investigated for dental applications in a number of interesting directions. Titanium oxide nanotubes have been shown *in vitro* to accelerate the kinetics of HA formation, mainly in a context of bone-growth applications for dental implant coatings. More recently, modified single-walled carbon nanotubes (SWCNTs) have been shown to improve flexural strength of RBCs. These SWCNTs had silicon dioxide applied to them in conjunction with specialized organosilane bonding agents.

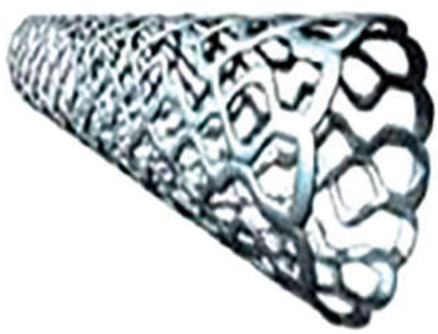

Fig. 3. Nanotubes

Nanofibers: More recently, nanofibers have been used to generate ceramics containing HA and fluor-HA. Nanofibrillar silicate crystals have also been recently studied in the capacity of reinforcement of dental composites, specifically a combination of the widely-used 2,2'-bis-[4-(methacryloxypropoxy)- phenyl]-propane (Bis-GMA) with triethylene glycol dimethacrylate (TEGDMA) added as a thinning agent. Added in the correct proportions and with uniform distribution of the fibres/crystals, nanofibers were demonstrated to improve the physical properties of these composites.

Advantages:

- Surface area to volume ratio
- All properties can be controlled
- Try to virtually imitate nature by constructing objects from basic components
- High degree of precision & control over final product.
- Better penetration to cells (Mahesh Mundathaje, 2015).

Nanotechnology in Prosthodontics

In prosthodontics, various types of nanomaterials are added to improve the properties of commonly used materials like resin denture base material, ceramics, polyvinyl siloxane impression material, maxillofacial materials, luting cements, etc. Research on addition of nanoparticles in this regard will promote the usage of such materials with greater efficiency and durability will definitely be of great advantage to dentists and patients undergoing prosthodontic treatment.

In removable prosthodontics: Incorporation of carbon nanotubes into heat cure monomer has reduced the polymerization shrinkage and improved the mechanical properties. Incorporation of metal oxide nanoparticles into conventional polymethyl methacrylate has improved the flexural strength, antimicrobial property and reduced porosity.
Main reasons for mechanical failure in maxillofacial prostheses include tensile and tearing loads. The use of polyhedral oligomeric silse squiox, as a reinforcing agent, has enhanced the tensile and tearing strengths of conventional materials. Nanocomposite denture teeth (Fig 4) are stain and impact resistant with lively surface texture (Gopinadh, 2015).

Fig. 4. Nanocomposite denture teeth

In fixed prosthodontics: The introduction of nano fillers into the resin matrix has led to the development of newer light cure nano composites with numerous advantages like Highest mechanical strength, Low polymerization shrinkage, Reliability, Durability, Low thermal expansion coefficient, Low water sorption, Excellent marginal integrity, and Excellent handling characteristics.

Fig. 5. Nanostructured implants

Nanosurface coatings of dental implant: The application of nano technology in dental implants can be made by coating of nano particles over the dental implants. It has been demonstrated that different cell types respond positively to nanotopography. The surface of the implant plays a critical role in determining biocompatibility and biointegration because it is in the direct contact with the tissues. Implant surface composition, surface energy, surface roughness and surface topography are the four material factors which can influence events at bone implant interfaces. Various surface textures have been created and used to successfully influence cell and tissue responses. The surface textures are of three types macro, micro and nano.

The nano structured materials (Fig 5) can exhibit enhanced mechanical, electrical, magnetic and optical properties compared with their conventional micro scale or macro scale counterparts. Nano structured materials contain a large volume fraction of defects such as grain boundaries, inter phase boundaries and dislocations and this strongly influences their chemical and physical properties. Biomimetic implant may be the next development in the field. Coating implants with nano textured titanium, hydroxyl apatite and pharmacological agents such as bisphosphonates may induce cell differentiation and proliferation, and promote greater vascularity in cortical bone thereby improving conditions for early and long-term bone remodelling (Kumar Saravana, 2006).

In maxillofacial prosthodontics: Various types of materials have been used for the fabrication of maxillofacial prosthesis. They are Polyvinyl chloride, Polymethyl methacrylate, Polyurethanes, Chlorinated polyethylene and silicones. Out of these materials, silicones are the choice of material for extraoral prosthesis fabrication due to its favourable properties like acceptable tear and tensile strength, chemical inertness, high elongation, ease of fabrication. However, there are several drawbacks like discoloration of the material, deterioration of the physical and mechanical properties, difficulties related to its repair which results in a short service life time thereby leading to the failure of the prosthesis.These materials undergo drastic changes in their structure and appearance during their lifetime, mainly due to aging caused by exposure to solar irradiation, temperature changes, humidity, etc. The best materials remain aesthetically suitable and functional for an average of only 1 to 2 years with a decline in patient satisfaction within 3 years of service. Hence, most silicone prostheses must be replaced frequently due to these drawbacks.

This frequent replacement is not always affordable for the patient.

Nano-oxides when incorporated into polymers provided materials with better strength and flexibility. The nanosized material particle results in the optimization of characteristics and controls the biological, mechanical, electrical, magnetic, and optical characteristics as well. Nano sized rutile TiO_2 and ZnO have a high ultraviolet (UV) absorbing and scattering effect that results in UV protection. Nano sized SiO_2, TiO_2, and ZnO are characterized by their small size, large specific area, active function, and strong interfacial interaction with organic polymer. Therefore, they can improve the physical properties and optical properties of the organic polymer, as well as provide resistance to environmental stress related aging. Silicone soft liners are most often used to line obturators to reduce the irritation and utilize the bony and soft tissue undercuts in the patient's mouth.
One of the main drawbacks seen with these soft liners is that they do not resist antimicrobial colonization. Microorganisms like Candida albicans not only adhere to the surface but also penetrate the soft liners. Silver nano particles (AgNPs) are used as antimicrobial agents in many medical fields. In vitro studies have shown the efficacy of silver NPs as antimicrobial agents. They reduce or prevent the biofim layer formation. Silver nanoparticles act by inhibiting the replication by binding to the microbial DNA and they also switch off important enzymes, leading to microbial death. In fact, this metal has a broad antimicrobial activity spectrum against both Gram-positive and Gram-negative bacteria (Sabarigirinathan *et al*., 2018).

Nanoparticles in impression material: Nanofillers are integrated in vinylpolysiloxanes, producing a unique addition of siloxane impression materials. The material has better flow, improved hydrophilic properties hence fewer voids at margin and better model pouring (Jhaveri, 2005).

Advantages: Increased fluidity, High tear resistance, Hydrophilic properties, Resistance to distortion,heat resistance, Snap set that consequently reduces errors caused by micro movements

Trade name

NanoTech Elite H-D+.
Imprint II Penta H

Nanoparticles in resins (polymethyl methacrylate): Currently, resin used in prosthodontics is mainly including polymethyl methacrylate (PMMA) and its modified products. They are widely used in making temporary prosthetic base materials, provisional prosthesis, dentures and orthodontic removable appliances such as retainers and functional appliances. The main component of PMMA is polymethyl methacrylate, also containing small amounts of ethylene glycol dimethacrylate. PMMA has good mechanical properties such as high hardness, rigidity, discontinuity deformation, biological properties, aesthetic properties, and easy processing characteristics. Disadvantages of PMMA are the instability of color, poor resistance to wear and tear, volume shrinkage after the polymerization, oral mucosa irritation, aging and relatively easy staining or discoloration. Recently, much attention has been directed toward the incorporation of inorganic nanoparticles into PMMA to improve its properties. Various nanoparticles such as ZrO2, TiO2, and CNT have been used to improve the performance of PMMA.

Titanium dioxide nanoparticles have been used as additives to biomaterials in order to induce antimicrobial properties against candida albicans, staphylococcus aureus, pseudomonas aeruginosa, escherichia coli, lactobacillus acidophilus, etc. Along with prominent catalytic effect, other characteristics such as white color, low toxicity, high stability and efficiency as well as availability have made titanium dioxide an appropriate antimicrobial additive for use in acrylic resin. Nanoparticles of silica dioxide possess extremely high surface activity and adsorb various ions and molecules.

Silver nanoparticles: Due to their small size possess greater dispersion in PMMA matrix and produce larger area for oxidation. The release of silver ions plays the major role in the antibacterial mechanism of silver nanoparticles by rupturing the cell wall causing protein denaturation, blocking cell respiration, and finally causing microbial death. However, disadvantages of silver nanoparticles incorporated in acrylic resin are also evident. The acrylic resin incorporated with silver nanoparticles experienced a color change (an important functional property of dental materials) resulting from the plasmon effect of the silver nanoparticles. Plasmonic effect is the interaction between free electrons in metal nanoparticles and incident light. This phenomenon was very significant for silver nanoparticles concentrations above 80 ppm. In dentistry, adhesion and plaque formation onto PMMA based resins is a common source of oral cavity infections and stomatitis. The addition of metal nanoparticles such as TiO_2, Fe_2O_3, and silver to PMMA materials could increase the surface hydrophobicity to reduce bimolecular adherence. Nanoparticles are added to polymethyl methacrylate as antimicrobial agents to increase the viscoelastic property of resins (Sabarigirinathan *et al*., 2018).

Tissue conditioner: Tissue conditioners have been commonly used to enhance the recovery of denture bearing tissues from trauma, damage or residual ridge resorption usually caused by ill-fitting dentures. However these materials are degenerated with time and are susceptible to colonization by microorganisms. Silver has been well known for its antimicrobial characteristic. So to overcome this problem silver nanoparticles are added in tissue conditioners because of their smaller size they provide large surface area.

Dental adhesives: Dental adhesives are the material used to promote adhesion or cohesion between two different substances or between a material and natural tooth structure. Polymerizablesilane is added to dental adhesives in order to increase the cohesive strength. Since the adhesive liquid are not very viscous the filler particles tend to settle out during storage which leads to inconsistency in their performance. To overcome this disadvantage discrete silane treated nanoparticles of silica or zirconia in the size range of 5-7 nm are added to dental adhesives.

Nanoparticles in dental cements: Antibacterial activity of dental luting cement is a very important property when applying dental crowns, bridges, inlay, onlay, veneers because bacteria may be still present on the walls of preparation or gain access to the cavity if there is micro leakage present after cementation.In order to overcome this, silver nanoparticles were added in dental cements. Silver has been used for its bactericidal properties for many years. Silver nanoparticles are used because of their advantage that they show strong antibacterial activity due to their higher surface area to volume ratio. Resin composite cement incorporated with silver-containing materials had a long term inhibitory effect against S. mutans and favorable mechanical properties (Scott, 2009).

Nanoceramics: Ceramics have been used in manufacture of dentures because of their high strength, suitable color, and low thermal and electrical conductivity. At present, ceramic dental crown is mainly including alumina ceramic and zirconia ceramic. Alumina ceramics have good aesthetics, high gloss, chemical stability, wear resistance, high hardness, good biocompatibility, no allergies and no effect on the MRI, but the biggest drawback is that it is likely toporcelain crack.ZrO_2 has a good abrasion resistance, physiological corrosion resistance and biocompatibility, whose modulus of elasticity, flexural strength, and hardness are higher, compared to those of HA and titanium alloys. The strength and bending resistance of zirconia ceramics through computer aided design/computer aided manufacture are significantly higher than alumina ceramic, but they still lack toughness and high sintering temperature. Nanostructured ceramics may meet the need for translucency of dental restoration.Nanoceramic refers to the ceramic material with nanoscale dimensions in the microstructures phase. Compared with the conventional ceramics, nanoceramics have unique properties like good toughness and ductility. Firstly, nanoceramics have superplasticity. Ceramic is essentially a kind of brittle material; however, nanoceramic shows good toughness and ductility. Secondly, compared to the conventional ceramics, nanoceramic has the superior mechanical properties, such as strength and hardness. The hardness and strength of many nanoceramics are four to five times higher than those of the traditional materials (Wang Wei, 2015).

Conclusion

Nanomaterials have been playing a significant role in basic scientific innovation and clinical technological changes in prosthodontics. It shows that many properties such as modulus of elasticity, surface hardness, polymerization shrinkage, and filler loading, of materials used in prosthodontics can be significantly improved after their scales were reduced from micron-size into nanosize by nanotechnology and that the performances of composites can also be enhanced by adding appropriate nanomaterials. However, further studies are required to clarify the cytotoxicity of various nanoparticles, optimal concentration and mechanical stability for proper and safe clinical experience.

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