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Nanotechnology - A new dimension in prosthodontics

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Abstract

Scientific discovery changes our perception, our way of thinking and our attitude about today and tomorrow. Keeping in mind the increasing number of beneficiary fields, we can establish the fact that even the field of dentistry is not spared. In recent years, lots of researches have been launched on nanomaterials for biomedical applications and 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. This paper is an attempt to give an overview about the nanotechnology, nanomaterials and its applications in the field of Prosthodontics.

Keywords: Nanoworld, Nanodentistry, Prosthodontics

Introduction

"You have to be able to fabricate things, you have to be able to analyze things, and you have to be able to handle things smaller than ever imagined in ways not done before" - Cloude Levi Strauss and Winfred Phillips.

At present the science is undergoing a great evolution, taking humanity to a new era, "The Era of Nanotechnology". Nanotechnology is the scientific ability to control and restructure the matter at the atomic and molecular levels within the nanoscale. Also, nanotechnology refers to using minute machinery that is capable of manipulating matter on an extremely small scale at dimensions between approximately 1-100 nm where unique phenomenon enables novel applications. In other terms Nano technology means science of small. [1]But how small is the nanoscale?? 1nm is 1 billionth a meter (10^{-9})

Why is nanotechnology important

Nanotechnology improves existing processes, materials and applications by scaling them down to the nanoscale in order to ultimately fully exploit the unique quantum and surface phenomena that matter exhibit at nano scale. Also,

nanotechnology establishes link between nanoscopic and macroscopic universe by inventing adequate methods.

And enables to arrange atoms as we desire and subsequently to achieve effective, complete control of the structure of matter.[2,3]

Developmental Process of Nanotechnology

Metals used in powder form used as medicine in Ayurveda (600-10000 BC). Metals & Powders were converted into very fine and absorbable powders which were therapeutically most effective and least toxic.[4]

In Modern Era the vision of Nanotechnology was born by Richard P Feynman (1959) who predicted the potential of nanoparticles in his historic lecture 'there is plenty of room at the bottom. Norio Taniguchi in 1974 defined Nanotechnology as process of separation, consolidation and deformation of material by one atom or one molecule. In 1981 Gerd Binnig and Heinrich Rohrer introduced scanning tunneling microscope which could image non-conducting organic molecules.[6]

Aims of nanotechnology

- To enable analysis of structures at Nanoscale
- To understand the physical structures at nano level dimension
- To manufacture Nano level structures
- To develop devices with Nano precision

Approaches used in nanotechnology[7,8]

1. Bottom-up technique
2. Top-down technique
3. Functional approach

Bottom-up approach: These seek to arrange smaller components into complex assemblies. Use chemical or physical forces operating at the nanoscale to assemble basic units into large structures. Example: Formation of carbon Nanotubes.

Top-Down Approach: These seek to create smaller devices by using larger ones to direct their assembly. The most common top-down approach involves lithographic patterning techniques using short wavelength optical sources.

Functional Approach: In this approach, components of a desired functionality are developed without regard to how they might be assembled.

Nanomaterials

Nanomaterials are classified as:

1. One dimensional
2. Two dimensional
3. Three dimensional

One Dimensional: It has only one parameter either length, or breadth, or height. E.g., Sheets or thin coatings.

Two Dimensional: It has only length and breadth. E.g., Nano wires & nano tube

Three Dimensional: It has all parameter of length, breadth and height. E.g., Nanoring Nanomaterials using plant extracts: Leave of Geranium plant (Pelargonium graveolens) have been used to synthesize gold nano particles. Plant associated fungus – produce compounds such as taxoland gibberlins.

Nanotechnology in Prosthodontics

Prosthodontics is the dental specialty pertaining to the diagnosis, treatment planning, rehabilitation, and maintenance of the oral function, comfort, appearance, and health of patients with clinical conditions associated with missing or deficient teeth and/or maxillofacial tissues by using biocompatible substitutes, fixed prosthodontics, implant prosthodontics, maxillofacial prosthetics, removable prosthodontics.[9]

Purpose of dental Prosthesis

Dental Prosthesis is to restore dental function as well as speech and facial appearance and maintain the wearer's health. These materials used for the fabrication of

prosthesis remains in direct contacts with the oral mucosa and is under long-term use in the oral environment.

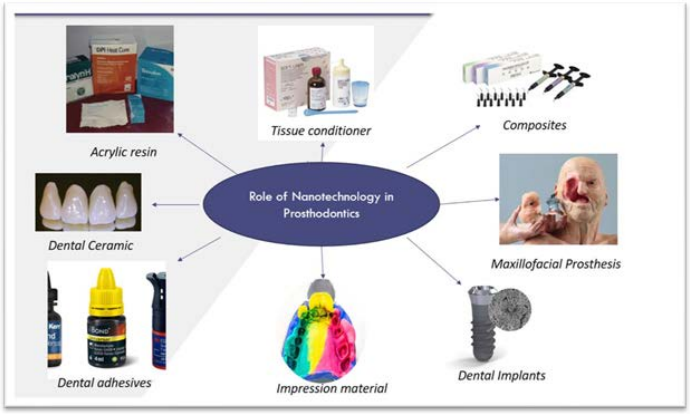
So, the dental materials must have comprehensive properties and good biological activity for their long-term use and to function properly.

Need for Nanotechnology in Prosthodontics

Materials reduced to the nanoscales can suddenly show a very different properties enabling unique applications. For instance,

1. Opaque substances become transparent (Copper)
2. Inert materials become catalyst (Platinum)
3. Stable materials turn combustible (Aluminium)
4. Solids turns into liquid at room temperature (Gold)
5. Insulators becomes conductors (Silicone)

Nanotechnology and its Prosthodontic application



Acrylic resin: The main component of PMMA is polymethyl methacrylate, also containing small amounts of ethylene glycol dimethacrylate.

Advantages: PMMA has good mechanical properties such as

- High hardness,
- Rigidity,
- Deformation,
- Good biocompatibility,
- Aesthetic properties, and
- Easy processing characteristics.
- Can be easily repaired

Disadvantages

- Poor strength particularly under fatigue failure inside the mouth
- Low abrasion resistance
- Microbial adhesion onto PMMA on long term usage.
- Instability of color.

Much attention has been directed toward the incorporation of inorganic nanoparticles into PMMA to improve its properties.Various nanoparticles such as Zro^2, Tio^2, and CNT have been used to improve the performance of PMMA, and the results showed that desired mechanical property enhancement can be achieved. Tio^2 nanoparticle reinforced the mechanical behaviour of PMMA. Well dispersion nano-Zro^2 particles can improve the modulus and strength and maintain or even improve ductility. Ag $Tio^2$and Fe^2 O^3 particles significantly reduce adherence of C.Albicans of PMMA and do not effect metabolism or proliferation. Study showed that addition of modified Zro^2 nanomaterials in different percentage (2 wt%, 3 wt%, and 5 wt%) to heat-cured acrylic resin PMMA materials results in increased abrasive wear resistance, tensile fatigue strength with 3 wt% and 5 wt% of nanofillers when compared to pure PMMA materials.[10]

Denture teeth

Wear resistance is the most desired physical property of denture teeth. Porcelain teeth are more wear resistant but they are brittle, bond mechanically to the denture base and difficult to polish. Acrylic resin denture teeth are easier to manipulate but undergo excessive wear. With introduction of Nano composite denture tooth comprises of polymethylmethacrylate and uniformly dispersed Nano sized filler particles.[11]

Advantages

- Highly polish able, stain and impact resistant material.
- Lively surface structure.
- Superior surface hardness & wear resistance.

Commercially available nanocomposite denture teeth: Veracia (Shofu, Japan)

Tissue conditioners: 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.

Drawbacks

- Tissue conditioners get degenerated with time and becomes hard.
- Also, they are more susceptible to colonization by microorganisms.
- Tissue conditioners could be kept clean by mechanical and chemical methods but this can cause considerable damage to tissue conditioners.

So, to overcome this problem silver nanoparticles are added in tissue conditioners which has antimicrobial properties. According to a study the modified tissue conditioner combined with silver nanoparticles displayed antimicrobial properties against S. Aureus, S. Mutans at 0.1% and C. Albicans at 0.5% after a 24 hrs and 72 hrs of incubation period.[12]

Dental Adhesive

Dental adhesives are the material used to promote adhesion or cohesion between two different substances or between a material and natural tooth structure.

Polymerizable silane 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. According to a study by N. Silikas *et al*., no decrease in bond strength of dental adhesives after the incorporation of silica or zirconia nanoparticles was obtained.[13]

Maxillofacial Silicone Prosthesis

Maxillofacial prostheses are made of artificial substitutes like silicone and used to replace facial parts lost through disease or trauma. They are also used to restore and maintain the health of the tissues and to improve aesthetics for better social acceptance of facial injuries.

Current materials used for maxillofacial applications experience some serious problems, particularly low tear strength, unacceptable color. Thus, it is necessary to have a material with satisfactory tear strength, tensile properties, appropriate hardness and color stability.

The ideal material should be similar to the missing facial tissue to optimally match a patient's articulate features of mastication, speech resonance, and facial gesture.

Consequently, there is a need for improved materials with superior physical and mechanical properties that are comparable to those of human tissues and skin.

SiO_2 nanoparticles are characterized by their small size, large interface area, active function, and strong interfacial interaction with the organic polymer. Therefore, they can improve the physical, mechanical, and optical properties of the organic polymer and provide resistance to environmental stress-caused cracking and aging.[14]

Nano composite resins [15,16]

Nanofill composites: Nanofills are the dental composites in which the fillers are of 1-100 nm range. Two types of nanoparticles are used for preparing nanofill dental composite. The *first* of these is the most common and are nanomeric particles which are essentially monodispersed non-aggregated and non-agglomerated particles of silica.

Advantages

- Optical properties are good.
- Dispersion rate is improved
- Increased polish retention
- Increased surface gloss

Disadvantages

- Rheological properties are poor
- Poor handling properties

The *second type* of nanoparticle used to prepare nanofill composites is nanoclusters. This is done in order to overcome the disadvantages of the previously used nanomeric nanoparticle.

Advantages

- Optical properties are good.
- Dispersion rate is improved
- Increased polish retention
- Increased surface gloss
- Rheological properties better than the previous one

Disadvantages

- Poor handling properties

Nanohybrid Composites: Prepolymerized organic fillers are incorporated so as to improve the undesirable rheological properties of composites where nanomers were included.

Advantages

- ✓ Improved esthetic properties
- ✓ Improved rheological properties

Disadvantages

- ✓ Dispersion rate is decreased
- ✓ Decreased polish retention and surface gloss

Titanium Di-Oxide Reinforced Resin Based Composites: These nanoparticles have been used to improve the microhardness and flexural strength of the resin-based composites.

Nanocomposite with Alumina Nanoparticles: Inclusion of alumina nanoparticles increases the hardness of the nanocomposite as compared to other nanocomposites.

Calcium phosphate and calcium fluoride nanoparticles-based composites: Materials that release calcium fluoride or phosphate ions have been shown to provide remineralization to tooth structure. Nanohydroxyapatites (HAP) having a particle size of 20 nm were synthesized to mimic the natural building blocks of human enamel and were found to provide anticaries repair effect.

Nano Impression Materials[17]: Vinyl polysiloxane (VPS) are currently the most used materials for making indirect restorations. They are available in many viscosities and a range of colors. These materials are highly hydrophobic. Improved physical properties of polyvinylsiloxane impression materials was done by addition of nano sized fumed silica – Better flow, improved hydrophilic properties, fewer voids at margin and better model pouring with enhanced detail precision. Choi JH et al have done a study in which polyvinylsiloxanes (PVS) were used as dental impression materials, formulated with the variation of loading combination of six types of fillers including nano-sized fumed silica. The fillers were blended with three types of silicone polymers together with cross- linker and inhibitor in base paste and with plasticizer and platinum results setting time became much faster.Ideal working and setting time for clinical use. Increases the viscosity Tensile strength and maximum% strain.

Impression materials Nanotech Elite HD+ from the company Zhermack is available with nanotechnology application. Here nanofillers are integrated in the vinyl polysiloxanes, producing a unique addition siloxane impression material having added advantages of:

Better flow - Improved hydrophilic properties hence fewer voids at margin and better model pouring.

Enhanced detail precision

Elite H-D + - snap set that consequently reduces errors caused by micro movements.

Elite H-D + is available in light fast, Light regular set, Medium and Heavy viscosities and is delivered in the new safety cartridges.

Nanoceramics[18]

Ceramics have been used in manufacture of dental prosthesis 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.

The development of ceramic crown experienced long essence of ceramic materials like Hydroxyapatite (HA) ceramic, Glass ceramic, Alumina ceramic, and zirconia ceramic. Traditional ceramics are made of clay and other natural occurring materials, while modern high-tech ceramics use zirconia, silicon carbide etc. Nanoceramic refers to the ceramic material with nanoscale dimensions in the microstructures phase.

ZrO^2

- ✓ Has a good abrasion resistance,
- ✓ Physiological corrosion resistance, and
- ✓ Biocompatibility
- ✓ Flexural strength, and hardness are higher.

The strength and bending resistance of zirconia ceramics through computer aided design/computer aided manufacturing are significantly higher than alumina ceramic, but they still lack toughness and high sintering temperature. *Glass ceramics* based on lithium disilicate with lack of mechanical properties are commonly used in dental veneers and crowns. Due to insufficient mechanical properties of glass ceramics, clinical failure has been often reported.

To improve mechanical properties of glass ceramics based on lithium disilicate, Persson et al. used a sol-gel method to produce glass ceramics in the zirconia-silica system with nanosized grains, which was found to be translucent, with a transmittance of over 70%, and possessed excellent corrosion resistance. It also presented a somewhat lower elastic modulus but higher hardness than the conventional lithium disilicate.

Unique properties of Nanoceramics

- ➢ Firstly, Nanoceramics have super plasticity.
- ➢ Shows good toughness and ductility.
- ➢ The arrangement of atoms in nanoceramics is such that they are very easy to migrate under force deformation.
- ➢ Superior mechanical properties e.g., such as strength and hardness increasing significantly. The hardness and strength of many nanoceramics are four to five times higher than those of the traditional materials.

Overall, with Nano research: The hardness and fracture toughness increased of nano-zirconia ceramics. Glass ceramics with nanosized grains showed excellent corrosion resistance, high fracture toughness, and translucency.

Addition of Nano fillers results:

- ➢ Enhanced polishability
- ➢ Reduce wear
- ➢ Nano pigments
- ➢ Adjust the shade of restoration to the surrounding tooth (Chamelon effect)
- ➢ Nano modifiers
- ➢ Increases the stability of the materials.
- ➢ Prevents sticking to instruments.

Nano Light cure Glass ionomer cement: Glass ionomers were introduced by Wilson and Kent in the 1970s as dental filling material. Mainly composed of powder and liquid.

Advantages

- Glass ionomers have excellent properties such as chemical bonding to the tooth structure
- Biocompatibility and Fluoride release.

Shortcomings

- Poor aesthetic
- Compromised mechanical properties and
- weaker bond strength

In order to improve the properties and to overcome these shortcomings, active research is in progress, such as in the addition of cellulose fibers, hydroxyapatite and fluoroapatite and nanotechnologies.

Luting agents based on nanotechnology are being produced for permanent cementing of conventional prosthesis including all ceramic constructions on aluminium oxide and zirconium oxides frames. This material displays high pulpal friendliness and also minimum leakage at the margin.

More recently, addition of nanoparticles resulted in the aesthetic improvement of the final restoration and polishablilty. Fluoride release property is not affected yet by the addition of nanoparticles due to the high surface area.

Dental Implant Surface modifications Nanotopographically[19]: Dental implant therapy has been one of the most significant advances in dentistry in the past three decades. Osseointegration is widely accepted in clinical dentistry as the basis for dental implant success. As we all know surface characteristics directly and indirectly influence the way of molecules present in the biological world and this might ultimately control new tissue formation as cell proliferation and differentiation both depend on quality of early adhesion. The most frequent cause of failure of implants is insufficient bone formation around the implant. Many research efforts have been directed toward improving the bone-implant interface, with the aim of accelerating bone healing and improving bone anchorage to the implant Surface properties of dental implants play an important role in biological interactions.

The nanometer sized roughness and the surface chemistry have a vital role in the interactions of surfaces with proteins and cells. These early interactions will in turn condition the late tissue integration.

With the introduction of nanotechnology Nanostructured hydroxyapatite and calcium Phosphates coating for dental implants, have attracted much attention. Hydroxyapatite and calcium phosphates coatings promotes bone formation around implant, by increasing osteoblasts function such as adhesion, proliferation and increases mineralization.

Role of Nanotechnology in current COVID-19 Scenario: As of now as we are moving towards pre-covid times & COVID -19 vaccination is playing a crucial role in returning life to normal, we can't neglect the role of nanotechnology in vaccination development. The COVID-19 pandemic has infected millions of people with no clear signs of abatement owing to the high prevalence, long incubation period and lack of established treatments or vaccines.

As of now it is proven that vaccines are the most promising solution to mitigate new viral strains. The genome sequence and protein structure of the 2019- novel coronavirus were made available in record time, allowing the development of inactivated or attenuated viral vaccines along with subunit vaccines for prophylaxis. Lipid nanoparticles are a vital component of the mRNA COVID – 19 vaccines, playing a key role in protecting and transporting the mRNA effectively to the right place in cells. They are next generation liposomes that uses nanotechnology and are well suited to stable and efficient delivery of various therapeutics.

Hazards: Nano technology carries a significant potential for misuse and abuse, if not properly controlled & directed. As we all know Nanoparticles have a large surface area, the more the surface greater the chance will be to increase the rate of absorption through skin, lungs, digestive tract. This could cause unwanted effects in the body as non-degradable nanoparticles could accumulate. Decreasing the size of the particle has been identified as main parameter for the increased toxicity of different materials.[20]

According to a study published Accumulation of these nano particles is seen in spleen, liver, kidney in animals. Also, the nanoparticles are so small that they can easily cross the blood-brain barrier. Proper care should be taken about nano particles and nanotechnology safety issues for personal health and safety of the workers who are involved in the nanomanufacturing processes and also the consumer to eliminate its effect on their health & environment.

What future holds for us

Nanotechnology is set to revolutionize clinical dental practice. The future holds in store an era of Prosthodontics in which every procedure will be performed using equipment and devices based on nanotechnology. With a diverse range of applications in all spheres, it has a capacity to change the world we live in. In no distant future, oral health care services will become less stressful for dental professionals, more acceptable to patients and the outcome will become significantly more favorable.

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