Applications of Nanotechnology in Prosthodontics

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ABSTRACT

Nanotechnology has profoundly affected almost every facet of science and development. Notably, the field of medicine and dentistry also are being influenced by nanotechnology utilizing its immense potential. Nanoparticles have proved to be much more potent as compared to bulk material. The unique size provides with much more room for modifying and enhancing various properties such as surface chemistry, charge, bonding capability along with various biological properties. The concept was initiated by late Nobel Physicist Richard P. Feynman in 1959. The field was explored in the subsequent years for the development of nanoscale machines as well as nano sized particles to achieve superior properties. Emphasis was on the basic mechanism of action and the approach of the material. Researchers have developed immense interest and pursued to apply the science of nanomaterials to various principles of cell transplantation, material studies and bioengineering. Development of more refined means of drug delivery at therapeutic levels to target sites, is an important concern in the medical and dental field. Inception of “nano dentistry” marks the future of near-perfect oral health conceivable using nanomaterials biotechnology including tissue engineering and nanorobotics. Routinely used dental materials having drawbacks of inferior physical and biologic properties have not been substituted rather can be modified with nanomaterials to enhance the inherent properties of the material within the economic limits. Unique characteristics of the nanoscale material may not only have profound effect on the physical properties such as tensile strength, fracture resistance, surface hydrophobicity, but also affect the biological properties like biocompatibility and cytotoxicity. Therefore, researcher's area of interest in the current times has been biological especially the cytotoxic effects of nanomaterials. A comprehensive research is therefore required for assessment of all the aspects of the nanoscale materials. This article is a brief overview of the philosophy and concepts of nanoparticles and their implications, especially on prosthodontics.

KEY WORDS

Nanoscience, Nanomaterials, Prosthodontics

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BACKGROUND

'Nano' simply means One Billionth / 10^{-9} / 0.000000001.¹

"Nanotechnology is engineering at the atomic and molecular scale." Materials fabricated at nanoscale demonstrate superior properties in comparison to their macroscale counterparts, facilitating exclusive applications. For instance, copper exhibits transparency when reduced to nanoscale; chemically inactive platinum may demonstrate catalytic properties at nanoscale; variations in the physical properties has been observed as in case of gold that turns in liquid at room temperature.^{2,3} The evolution for nanotechnology dates to around late 19th century. The term "nanotechnology" was conceived and popularized by Prof. Kerie E Drexler in 1977.⁴ The potential benefit includes its capability to make use of the atomic and molecular properties of materials and to foster advanced materials with enhanced properties.

The growth of nanotechnology and scope of its application has revolutionized the medical field progressing to emergence of "Nanomedicine" that is- "applications of nanotechnology for treatment, diagnosis, monitoring and control of biological systems". Similarly, development of "nano dentistry" will make the preservation of near-perfect oral health conceivable using nanomaterials biotechnology including tissue engineering and nanorobotics. Novel treatment modalities have been suggested in literature, such as remineralization, tooth hypersensitivity, orthodontic nanorobots, dental cosmetics, local anaesthesia, photosensitizer carriers, impression materials, nanoencapsulation, nanoneedles, bone replacement materials and dentifrices etc.

Prominent developments are the nanocomposites, bonding agents, emerging of link between biomolecules and nanotechnology through the generation of biomaterials.⁵ Nanorobots possess the ability to swim about thus enabling it to cross over and reach the surfaces that are beyond the scope of toothbrush bristles or dental floss. They could be built to serve short term purposes as daily hygiene measures to prevent tooth decay and periodontal breakdown at an early age. These nanorobots generally wane off in the oral cavity itself in the form of dietary fibers.⁶ They have also been proposed to be applicable to gerontological use, pharmaceutical research, and clinical diagnosis.^{7,8,9,10} In the field of implantology, the nanomaterials have been observed to demonstrate regenerative properties of both hard and soft tissues around the implant site.^{8,9} Also, the ability of new tissue growth that could replace the implanted biodegradable material supplies an array of new prospects in the area / branch of tissue regeneration.

This article reviews the concept of nanomaterials and its application in the prosthodontics.

WHAT IS NANOTECHNOLOGY?

"Nanotechnology is the engineering of functional systems at the molecular scale." In its original sense, 'nanotechnology' refers to the projected ability to manufacture materials from the bottom-up, using recent techniques and tools to develop complete, high quality products. The unifying theme is the control of matter on the molecular level in scales smaller than

1 micrometre, normally 1 to 100 nanometres, and the fabrication of devices within that size range.^{11,12}

Nanotechnology fundamentally changes the health care in following ways:

1. New diagnostic and preventive modalities.
2. Customized treatment plan in accordance with the patient's profile.
3. Drug delivery and gene therapy¹³

Modes of Nanotechnology

Broadly, nanotechnology is based on three mutually overlapping and powerful molecular technologies:

1. Nanoscale-structured materials and devices developed for advanced diagnostics, targeted drug delivery and smart drugs.
2. Molecular medicine via genomics, proteomics, artificial biotics (microbial robots).^{12,14}
3. Molecular machine systems and medical nanorobots allow instant pathogen diagnosis and extermination, and efficient augmentation and improvement of natural physiological function.

Concept of Nanomaterials

Nanoscale materials enables unique applications due to the variations observed in its physical properties.

The fundamental properties of the nanomaterial includes⁹-

- Small size effect,
- Quantum size effect
- Quantum tunnelling effect
- Surface effect

The small size effect¹⁵ is the minimum amount of energy that is required for interactions between nanoparticles (interactions like dissolution, melting, boiling, bonding, molecular reactions). This effect can be of particular use in the dental materials to improve flexure strength as unlike the usual sized particle they do not resist the shear strength rather get accommodated to it. Also, the extensive aggregation prevents the material from developing discontinuity that is the quantum size effect. The quantum tunnelling effect is that when a nanoparticle is made to pass through a thin barrier (eg. a cell membrane) it would not require much energy as it passes through the area of least resistance (the membrane in this case), this phenomenon explains the antimicrobial activity by membrane disintegration. The surface effect can be explained by the fact that nanoparticles have multiple surfaces which leads to more area for interactions (precisely the high surface energy).

ULTRA-STRUCTURAL CLASSIFICATION OF NANOPARTICLES

It can be based on multiple factors, primary being the classification based on the shape and ultra-nanostructure.

1. Nanorods

Dimensions: Length: 10 - 120 nm.

These are structurally like the enamel rods. Enamel-prism like hydroxyapatite nanorods exhibiting self-assembly properties were synthesized by Chen and colleagues.

Material: Metal and metal oxides, carbon.

Application: Drug delivery, bio-imaging, photothermal therapy nanocapacitors.

2. Nanowires

Dimensions: Diameter: 10 nm

Length: Not defined.

Material: Ceramic, metal oxide and metals.

Application: Magnetic devices, nanowires battery, nanogenerator, semiconductor, etc.

3. Nanotubes

Dimensions: Expressed in terms of ratio (length / width): 3 - 5

Available as single or multi-walled tubes.

Material: Carbon.

Application: Scaffolds or templates for the building.

Nano-Dentistry

Nano-dentistry offers the possibility of maintaining a near-perfect oral health, inclusive of application of nanorobotics and tissue engineering. The varying trends of oral health and diseases demand a need to shift the focus onto specific diagnostic and treatment modalities. The basic concept is to construct a fundamental structure using individual molecules and atoms.

The production of an array of various nanoscale structures is the primary target of current research. Primarily, the fabrication techniques can be categorized into two approaches.

The two approaches are

- 1) Top-Down approach
- 2) Bottom-Up approach⁶

NANORODS	NANOWIRES	NANOTUBES
•Dimensions – Length: 10-120 nm. •These are structurally like the enamel rods. Enamel-prism-like hydroxyapatite nanorods exhibiting self-assembly properties were synthesized by Chen and colleagues. •Material – Metal and metal oxides, carbon. •Application – Drug delivery, bio-imaging, photothermal therapy nanocapacitors.	•Dimensions – Diameter: 10nm •Length: Not defined. •Material – Ceramic, Metal oxide and metals. •Application – Magnetic devices, nanowires battery, nanogenerator, semiconductor, etc.	•Dimensions – Expressed in terms of ratio (Length/Width): 3-5 •Available as single or multi-walled tubes. •Material – Carbon. •Application – Scaffolds or templates for the building.

Ultra-Structural Classification of Nanoparticles

Top-Down Approach

The top down techniques that are used to manufacture nanoscale structures are mostly extensions of methods already employed in small scale assembly at the micron scale. By further miniaturization, the nano dimension is entered. Nano-dentistry as top-down Approach:

- Nanocomposites.
- Nanosolution.
- Impression materials.
- Nanoencapsulation.
- Nanoneedles.
- Bone graft materials.³
- Other products.

Bottom Up Approach

Bottom up approach deals with fabrication methods for manufacture of the nano goods and the methods used for producing nanoscale structures.

Nano dentistry as bottom-up approach:

- Local anaesthesia.
- Hypersensitivity cure.
- Nanorobotic dentifrice [dentifrobots].
- Dental cosmetics.
- Orthodontic treatment.
- Photosensitizers and carriers.
- Diagnosis of oral cancer.
- Treatment of oral cancer.³

NANOMATERIALS IN PROSTHODONTICS

1. Nanoimpression Materials

Nanomaterials can be employed to customize impression materials. A unique addition siloxane impression material is developed using the nanofillers for improved accuracy.

Advantages

- Better flow characteristics.
- Reduced number of void as a result of enhanced hydrophilic properties.
- Improved accuracy.

2. Nanometals

Removal Partial Denture Framework

Generally, cobalt based alloys are used for fabrication of metal stents of partial denture framework. The development and application of cobalt chromium molybdenum alloy from its binary alloy versions have shown to display superior mechanical properties and corrosion resistance in comparison to the traditional stainless steel and gold alloys.^{6,15}

Modification of Titanium Surface (Implant)

Though titanium has superior properties like specific strength, high corrosion resistance, good biological security and elastic modulus, biological integration is the most crucial element for perennial success of implants. Therefore, use of titanium nanoparticle was experimented by Dorkhan et al in his study. He carried out anodic oxidation to modify the surface of titanium implant into nanoscales with 50 nm range pores. It was noted that similar level of adherence of soft-tissue cells i.e.

keratinocytes and fibroblasts amongst altered and unaltered implant surfaces. While, attachment of oral streptococci was significantly lower on the nanostructured surface.¹⁶ Anodization is a simple and less expensive process to promote osteoblastic adhesion according to the various studies. This was demonstrated by Yao et al (2015) in his study to create nano-surface on titanium and Ti6Al4V implant by anodization. It was observed that the altered surface displayed higher roughness at nanoscale dimensions as compared to the un-anodized Ti-based surfaces. Thus, enhancing osteoblastic adhesion on the anodized metal substrates.¹⁷

3. Nanoceramics

Routinely used alumina ceramics though have superior mechanical properties but one of its major drawbacks is that it is more likely to crack. Zirconia ceramics have significantly overcome the shortcomings of alumina ceramics, but they lack toughness. "Nanoceramic" refers to "the ceramic material with nanoscale dimensions in the microstructures phase".¹⁸ primarily the property of brittleness causes the shortcoming of ceramic material; however, nanoceramic demonstrates improved toughness and ductility, this is attributed to the atomic arrangement in nanoceramic interface. Series of studies were conducted with regards to toughness and strength of nanoceramics like, Wang et al (2006) in his experiment, compared addition of 20 % of Nano ZrO₂ to a composite of AL₂O₃ and conventional ZrO₂ in terms of toughness. Nanoceramic yielded better results.¹⁵

Li et al (2011) through his study revealed the hardness of traditional ZrO₂ was 1500 while that of nano ZrO₂ is 1750.³ V. Raj et al (2014) compared the micro hardness and toughness of conventional TiO₂ ceramics Vs nano TiO₂ ceramics. Nano TiO₂ exhibited 13000 kN / m² micro hardness and superior hardness while conventional TiO₂ ceramics had value less than 2000 kN / M².²

In general, the advantages of nanoceramics that could be summarized are:

1. Super plasticity.
2. Superior mechanical properties

4. Nanoresins

Poly Methyl Meth-Acrylate [PMMA] inherits good mechanical properties such as high hardness, rigidity along with enhanced biologic properties like biocompatibility, aesthetics, and it possesses easy processing characteristics.¹⁹ The major drawbacks include instability of colour, poor wear resistance, volumetric shrinkage, oral mucosa irritation, and discoloration. Low fatigue strength, low abrasion resistance and microbial adhesion are the other disadvantages of PMMA. Fusion of PMMA and nanoparticles display an array of superior properties. Nanoparticles like TiO₂, ZrO₂, CNT (Carbon Nano Tubes) have been used to enhance PMMA material.^{2,15} Hua et al (2013) performed a study in which the saturation of reinforcing effect was studied for conventional PMMA and TiO₂ reinforced PMMA. Results were:

1. A nano particle with aspect ratio larger than 30 could nearly make the reinforcing effect reach saturation.
2. Saturation at 3 % volume increase is equivalent to 6 % volume increase of glass fibre.

Cooper et al (2002) showed that addition of small amount of CNT will significantly improve the impact strength of PMMA. Hong et al (2003) added Methacryloxy-Propyltrimethoxy-Silane (MPS) modified silica nanoparticles to PMMA which increased the tensile strength and tensile modulus.¹⁶ Mudhaffar (2012) evaluated the effect of addition of different percentage of modified ZrO₂ to heat activated PMMA. He concluded that significant results were obtained at 3 % and 5 % nanofillers in terms of abrasion resistance, tensile and fatigue strength.^{6,15,18}

In the quest of exploring the antimicrobial properties of nanoparticles, Yoshida et al (1999) demonstrated a long-term inhibitory effect of resin composite admixed with silver nanoparticles against *S. mutans*.¹ Laura et al (2011) prepared the PMMA composites along with addition of TiO₂ and Fe₃O₂ nanoparticles, for enhanced aesthetic as well as antimicrobial properties. The study concluded that PMMA containing nanoparticles demonstrated decreased rate of *Candida albicans* (*C. albicans*) cell adhesion and a reduced porosity as compared to standard / control sample.³

5. Nanomaterials in Maxillofacial Materials

Meran et al (2017): conducted an in-vitro study to check the efficacy of silver nanoparticles against *C. albicans* by coating it on silicone, the study was carried out of human fibroblasts⁶. He observed that the AgNP coating effectively prevented the fungal growth as determined by measurements of ethanol production by the yeast, without any cytotoxic damage to the fibroblasts. Shakir DA et al (2018) analysed the changes in the physical properties like tear strength, tensile strength, elongation percentage, and hardness of Room-Temperature-Vulcanized (RTV) VST50F and High Temperature-Vulcanized (HTV) Cosmesil M511 maxillofacial silicone elastomers after addition of Titanium Oxide (TiO₂) nanofillers. The findings of the study were:

Statistically significant improvement was observed in the mean values of physical properties such as tear strength, tensile strength, elongation percentage, and hardness of the materials after the addition of 0.25 wt % and 0.2 wt % TiO₂ nanofiller into VST50F and Cosmesil M511 elastomers, respectively.¹³

Category	Nanomaterial Used	Property Improved
Nano metals	Deposition of nanostructure Ti on the surface of pure titanium, Ti6 Al4 V and CoCrMo surfaces	Decreased adhesion of oral streptococci on the altered i.e., nanostructured surfaces than on the control counterpart, increased adhesion to osteoblasts
	TiN, ZrO ₂ /Al ₂ O ₃ , Si ₃ N ₄ /TiO ₂ , and ZrO ₂ /SiO ₂	Increases wear resistance
Nano Ceramics	ZrO ₂	Increases the hardness and toughness of the ceramic
	Zirconia-Silica sol-gel nano addition	Higher hardness
	Hot presses Alumina-CNT	Improved tribological and mechanical properties
Nano Resin	TiO ₂ reinforced PMMA	Increases the saturation per unit area in polymers
	TiO ₂ and Fe ₃ O ₂	Increased Anti-fungal property against <i>C. Albicans</i>
	Ag-PMMS nanoparticles	Improved anti-microbial properties
Summary of Nanomaterial Used in Prosthodontics.		

Abbreviations

1. ZrO₂ - Zirconium Oxide

2. TiO₂ - Titanium Oxide
3. Al₂O₃ - Aluminium Oxide
4. Fe₃O₂ - Ferrous Oxide
5. MPS - Methacryloxypropyltrimethoxysilane
6. PMMA - Polymethylmethacrylate Resin

CONCLUSIONS

Although the effect of nanotechnology on dentistry is limited at present, rapidly progressing research will ensure that nanotechnology is going to be the next big thing. It will have a far-reaching effect on oral health and developments which seem unrealistic today will help to achieve a near perfect oral health in future. As with all emerging technologies, a successful future for nanotechnology in dentistry will only be achieved through exchange of ideas and research findings.

Fate of expansion of prosthodontics technology is interlinked with the development of material science. Nanomaterials have been the forerunner in basic scientific innovation is an important advance in prosthodontics. Incorporation of nanoparticles enhance many mechanical properties of various dental materials applied in the field of prosthodontics.

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