Review Article

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# Era of Nanotechnology in Modern Prosthodontics

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## Abstract

Science has a profound effect on human life. Science makes the world, a better place to live in. Since the era of evolution, science has made a tremendous impact on human lives. Growing interest in the field of molecular science has led to the emergence of Nanotechnology, which has great medicinal as well as dental applications. Utilizing nanoparticles which are less tha 100nm in size nanotechnology has opened the gates of Nano dentistry which will help make products that are more reliable, treatments with better predictions and safe. Development of nanodentistry will make possible the maintenance of near perfect oral health. This review describes the Prosthodontic aspects of nanotechnology.

**Keywords:** Dental implants, Nanotechnology, Prosthodontics, Osseo integration

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## Introduction

As the saying goes, the more you know, the more you know you don't know. The inquisitive mind of human has always led to discovery of something new in the field of science. Today science has a profound effect on the way we live, largely through technology and the use of scientific knowledge for practical purposes. Nanotechnology is a field of applied science and technology, with the main unifying theme to control matter on a scale smaller than 1micrometer, between the range 1-100nm [1].

The term nanotechnology was coined and popularized by Prof. Kerie E Drexler in 1977. 'Nano' is derived from the Greek word for 'dwarf' [2]. Nanotechnology is distinguished primarily by the scale, at which it acts; one billionth of meter or one-ten thousandth width of a human hair involving individual atoms and molecules [3].

The late Noble prize laureate Prof. Richard Feynman had a vision that smaller and smaller machines could be created to work at the molecular level. In 1959, Prof Richard Feynman presented a talk entitled, 'There is plenty of room at the bottom', proposing the use of machines to make smaller machine tools which will in turn be used to make still smaller machine tools all the way down to the molecular level [4].

Nano dentistry will make possible the maintenance of near perfect oral health through the use of nanomaterial's, biotechnology and Nano robotics. Oral health and disease trends may change the focus on specific diagnostic and treatment modalities [5].

### Historical Development of Nanotechnology

Robert A. Freitas (2000) - deliberated about nanotechnology and its future application leading to the field of Nano medicine coming to light [6]. A field where nanostructured material and technology would be used to diagnose, treat and even prevent disease thereby improving human health.

George M White Sides, J Christopher Love (2001) gave voice to nanofabrication and its methods which can be categorized into top down and bottom up approach [4]. One beginning with a pattern generated on a larger scale and reduced to its lateral dimension while the latter starts from atoms or molecules to build up nanostructures.

Shiro Suzuki (2004) assessed the wear resistance of nano composite denture teeth. Four different types of denture teeth (nano filled and micro filled composites, cross linked acrylic and conventional acrylic with flattened buccal surface were subjected to evaluation of Knoop hardness (n=5) and localized wear of 1,00,000 cycles (n=10) [7]. Wear values were determined in micrometers using profilometer. It was concluded that, nanocomposite tooth was harder and more wear resistant than the acrylic teeth.

Chih- Yao Chiang et al., (2009) - conducted a study to improve the human cell growth on titanium used for dental implants by formation of a nano network surface oxide layer created by electrochemical anodization treatment [8]. The study concluded that TiO2 formation on titanium surface increased the human bone marrow mesenchymal stem cells growth both in vitro and invivo.

HHK Xu et al., (2010) reviewed the studies conducted on the synthesis of novel calcium phosphate and calcium fluoride nanoparticles and their incorporation into dental resins to developnanocomposites and improve its mechanical properties [9]. He concluded stating that the combination of releasing nanofillers would help making nan composites with better stress bearing and caries inhibiting capability.

Laura S Acosta - Torres (2011) - studied the use of nanostructured materials, TiO2 and Fe2 O3 for coloring and improving the antimicrobial properties of PMMA resins [10]. Nanoparticles of metal oxides were included during suspension polymerization to produce hybrid metal oxides- containing PMMA. The study reported that the introduction of biocompatible metal nanoparticles is a acceptable method for improvement of conventional acrylic dental resins.

Ahmad Sodagaret al., (2012) - studied the effect of silver nanoparticles on the flexural strength of poylmethyl methacrylate [11]. Acrylic liquid containing 0.05% and 0.2% silver nanoparticles was prepared for two kinds of acrylic resin: Rapid Repair and Selecta Plus. 15 acrylic blocks were prepared and evaluated. Addition of silver nanoparticles to Selecta Plus increased its flexural strength but addition of 0.05% nanoparticles was more effective than 0.2%.

Tahereh Ghaffari et al., (2014) - investigated the effect of adding silver nanoparticles to polymethyl methacrylate at 2% and 0.2% concentrations on compressive and tensile strength [12]. The silver nanoparticles were mixed with heat cured acrylic resin in an amalgamator in two groups at 0.2 and 2 wt% of silver nanoparticles. The study showed that the mean compressive strength of PMMA reinforced with AgNPs was significantly higher than that of the unmodified PMMA ($P<0.05$). The tensile strength was not significantly different between the 0.2% group and unmodified PMMA and it de-creased significantly after incorporation of 2% AgNPs ($P<0.05$). Based on the results the author stated that, silver nanoparticles improve the compressive strength of PMMA and can be used in palatal area of maxillary acrylic resin denture.

Tahereh Ghaffari et al., (2016) - conducted a study with the aim to compare the flexural strength and thermal conductivity of conventional acrylic resin and acrylic resin loaded with Nano clay [13]. The methacrylate monomer containing the 0.5, 1 and 2 wt% of Nano clay was placed in an ultrasonic probe and mixed with the PMMA powder. One way ANOVA was used for statistical analysis. The results stated, increasing the concentration of Nano clay incorporated into the acrylic resin samples increased thermal conductivity but decreased flexural strength.

## Nano Dentistry

The term nan dentistry was introduced to a larger community by the cover story of Freitas Jr. in the Journal of the American Dental Association more than a decade ago [14]. He developed his vision to use dental nan robots for orthodontic realignments in a single office visit, for dentition regeneration and oral health maintenance. He also elucidated the role of nanomaterial's and tissue engineering. Finally, he pointed out that properly configured dentifrobots will identify and destroy pathogenic bacteria residing in the plaque and elsewhere. The era of Nanodentistry was thus bought to light.

Development of "Nano-dentistry" will make possible the maintenance of near-perfect oral health through the use of nanomaterials, biotechnology including tissue engineering and nano robotics.

## Need for Nanomaterials in Dentistry

There is no ideal material for dental application till date, considering the understanding of various materials and the chemical properties with recent improvements in the physical properties. For instance, the composite materials have good aesthetic property but are still very technique sensitive and lack mechanical properties. There is no single synthetic material that can respond to external stimuli and act like nature made tissue. Nanomaterials are surrounded with high ambitions in terms to either develop new material or remarkable improvement in the existing materials [15].

## Nanotechnnology and Prosthodontics

Prosthodontics, an integral part of dentistry has received wide spread attention due to the increasing standard of living and oral health awareness among the masses. Since prosthodontics deals with fabrication of prosthesis for treatment of dental defects such as tooth loss, maxillofacial defects and temporomandibular joint disorders, it is of utmost importance for the materials used to have good biocompatibility, safety and function. The developments of nanomaterials having small size, but larger surface area have sparked research in the field material science including biomaterials [16].

## Nanomaterial Application in Prosthodontics

### Nanotechnology and Dental Implants

One of the major tests of Implantology is to achieve and maintain Osseo integration. Osseo integration is apparent direct attachment or connection of osseous tissue to an inert, alloplastic material without intervening fibrous connective tissue [17]. The structural and functional fusion of the surface of dental implant with the surrounding bone is a major factor in determining the long and short term success of dental implant.

The initial step of osseointegration is primary stability, which is mechanical and related to mechanical anchorage, design of the dental implant and the quality of bone. With time the primary stability decreases, as secondary anchorage which is more of biological process takes over. The secondary anchorage is characterized by biological bonding at the bone tissue and implant surface. The duration between the transitions from primary to secondary stability is when the implant is exposed to decreased stability. The goal of nanotechnology application in dental implants is to provide implant surfaces with better biological properties for the adsorption of protein, adhesion and differentiation of cells and tissue integration [18]. Implant surfaces can be characterized at macroscopic and microscopic level with the aim of improving the implant surface for better Osseo integration. At macroscopic level, the screw designs, the thread shape and the pitch distance give stability to implant [19]. Dental implant should be designed to maximize favorable stresses and minimize undesirable stress along the bone implant junction.

#### Nano Surface Modification

Biological interactions are greatly influenced by the surface properties. Modifying surface properties of dental implants have shown to have better bone to implant contact thereby improving their clinical performance. Nano features can be created on dental implants by either chemical or physical processes. Chemical processes such as anodization, acid etching, chemical grafting and ionic implantation, whereas physical processes such as plasma spray and grid blasting can be applied for surface modification.

**a.Anodization** - is one of the most prevailing method to create nanostructures with diameters less than 100nm on titanium implants [20]. Voltage and galvanic current are used to thicken the oxide layer on the implant surface. The titanium substrates serve as the anode in the process, while an inert platinum sheet provides the cathode. The anode and cathode are connected by copper wires and linked to a positive and negative port of a 30 V/3 A power supply. The cathode and anode submerged into an electrolyte solution in a Teflon beaker are kept at a distance of 1cm apart. Diluted hydrogen fluoride is used as an electrolyte. A strong acid dissolves the oxide layer resulting in a pattern formation guided by the lines of galvanic current. It enhances the cellular behavior by intensifying the osteoblastic cell growth and limiting the proliferation of fibroblast.

**b. Acid etching** - use of strong acids are effective in creating a thin grid of Nano pits on a titanium surface. Samples are etched with strong acid such as sulphuric acid (H2SO4) and hydrogen peroxide at a constant temperature for specific duration which is then halted by addition of distilled water. The samples are then washed with ethanol in an ultrasonic bath for 20mins and dried. Nano patterns created on titanium screw shaped implants have shown to have better osteointegration.

**c.Plasma Spray** - the process starts by using vacuum to remove all the contaminants, kinetic energy than guides the charged metallic ions or plasma to the surface. A variety of material such as Ag, Au, Tietc can be coated using this technique.There is sizeable literature that state, a thin layer of calcium phosphate (CP) coating on dental implants have encourage bone tissue formation over a period compared to uncoated. The CP coating dissolves and releases $Ca^{2++}$ and HPO42-which in turn increases the saturation of blood in peri - implant region. The biological apatite layer thus formed enhances cell adhesion, differentiation into osteoblast and synthesis of mineralized collagen. In addition to dissolution, osteoclast cells resorb the coating and activate osteoblast cells to produce bone tissue. CP coating therefore promotes a direct bone- implant contact [19]. Advantages of plasma spray are seen during healing which is decreased considerably and bone remodeling period.

**d.Grid blasting**- A porous layer is created on the implant surface by collision of microscopic particles in this process. Aluminia is the most prevalent material used for blasting. Modifying the granulometry of the particles the thickness of the porous layer can be modified. The surface of commercial endosseous titanium implants is a rough porous layer ranging between 50-200nm.

## Nanotechnology and Polymethylmethacrylate resin

Polymethylmethacrylate resin is one of the most widely used materials in dentistry since 1930 for the fabrication of denture bases. This is mainly due to its aesthetic, ease in production, processability and reparability. PMMA though has good dimensional stability, low water sorption and biocompatible has some disadvantages such as low resistance to fracture and poor antimicrobial properties. Any type of fracture in the prosthesis is time consuming to repair, costly and most importantly inconvenient to the patient. Use of nanotechnology will help develop PMMA which will be more biocompatible with better mechanical properties [21].

### Various Nanomaterials used in PMMA

#### a. Carbon Nanotubes and PMMA

Studies have suggested that carbon nanotubes are 10-100 times higher than steel at a fraction of the weight when incorporated in PMMA, which will help enhance its properties. Carbon nanotubes (CNT) are strong, resilient and very light weight.

CNT are available in two types:

(1) single walled which possess the basic cylindrical structure.
(2) multiwalled which are made up of two or more coaxial cylinders.

Saad Bin Qasim et al., from his study concluded that, light cure denture resin reinforced with carbon nanotubes showed better impact and flexural strength [21].

Kyoung - Im Kim 22 successfully developed CNT-PMMA which was drug free having antimicrobial adhesive properties to prevent microbe-induced complication [22]. However one of the major drawback of CNT incorporated PMMA is blackening of the prosthesis.

#### b. Silver Nanoparticles and PMMA

A.F Wady et al., evaluated activity of a silver nanoparticle solution against candida albicans and the effect of incorporation of silver nanoparticles into a denture base acrylic resin on the materials hydrophobicity [23]. It was concluded that inclusion of silver nanoparticles reduced the hydrophobicity of the resin thus stating that silver nanoparticles had antifungal activity. Tahereh Ghaffari et al., investigated the effect of adding silver nanoparticles to polymethyl methacrylate at 2% and 0.2% concentrations on compressive and tensile strength [12]. The silver nanoparticles were mixed with heat cured acrylic resin in an amalgamator in two groups at 0.2 and 2 wt% of silver nanoparticles. The study showed that the mean compressive strength of PMMA reinforced with AgNPs was significantly higher than that of the unmodified PMMA ($P<0.05$).

## Nanotechnology and Composite

Lately efforts have been made to develop a restorative material that shows physic-mechanical properties similar to that of a natural tooth structure. Concerned areas of improvement include reduction in polymerization shrinkage, improved mechanical properties, wear resistance and biocompatibility. Rationale for incorporating nanoparticles in composite is to improve the esthetic property of the material and increase its mechanical properties.

#### a. Use of Polyhedral Oligomeric Silsesquioxane (POSS) in Composite

Polyhedral oligomericsil sesquioxanes (POSS) is one typical organic–inorganic hybrid nan composite, which has been developed since the end of last century. POSS is a nanostructural chemical whose molecule is 1.5nm isotropic in structure. POSS monomer is represented by the empirical formula (RSiO1.5)n with an inorganic silica-like core (SiO1.5) surrounded by eight organic corner groups R [24].

Sellinger et al., was first to mention the use of POSS in dental restorative material [25]. Fong et al., evaluated the mechanical properties of dental nanocomposties reinforced with POSS [26]. In his research, POSS-MA was used to partially (or completely) replace Bis-GMA. The results showed that only a small percentage of POSS-MA substitution of Bis-GMA in the resin systems could improve the mechanical properties of the composites.

Xiaorong Wu et al., in his study found that nanocomposites reinforced with 2 wt % POSS showed an increased flexural strength by 15%, compressive strength by 12%, compressive modulus by 4%, hardness by 15% and a decrease in volumetric shrinkage of 56% [24].

## Nanotechnology and Impression Material

Impression material have not remained untouched by nanotechnology. Nanofillers are incorporated in impression material in order to enhance their property. An example of commercially available impression material reinforced with nanofiller is Nanotech Elite H-D [26].

Nanotech Elite H-D a product of Zhermack incorporates Nano fillers in vinyl polysiloxanes. This silicone has an increased fluidity, high tear resistance, resistance to distortion and better hydrophilic properties. Production of infinitely small details which reducing

errors caused by micro movements is one of the major advantage of this product. The material is available in light fast, light regular set, medium and heavy viscosities.

### Nanotechnology in Glass Ionomer Cement

One of the most frequently used material in dentistry are dental cements. There is no single cement which is ideal and fulfill all the requirements, thus on basis of their properties cements are given various applications. Retention of a restoration is one of the major function of dental cement. Various materials such as glass ionomer, compomer, zinc phosphate, zinc poly-carboxylate are used for permanent cementation of prosthesis [15].

Glass Ionomer Cement (GIC) invented by Wilson et al at the Laboratory of the Government Chemist is water-based cement also known as polyalkenoate cement. They have unique property such as, adhesion to moist tooth structure and base metals, anticariogenic properties due to fluoride release, thermal compatibility with tooth enamel, biocompatible and less toxic. Nevertheless, their use as a restorative material in stress bearing areas is limited due to its poor mechanical strength [27].

Nano modification of conventional GICs and resin modified GICs can be achieved by incorporation of nano sized fillers. Incorporation of nanosized fillers will not only increase its mechanical properties but also enhance fluoride release and bioacitivity [28].

Nano fillers can occupy the empty spaces between the particles and act as a reinforcing material. Nano light curing glass ionomer restorative blends nanotechnology originally developed for Filtek™ Supreme Universal Restorative with fluoraluminosilicate (FAS) technology, has excellent polishability, improved esthetics and wear resistance [27].

## Challenges Faced by Nanodentistry

The use of nanotechnology in dentistry has taken the field by storm; there are still various challenges at engineering, biological and social level. Feasibility of mass production, positioning and assembling the molecular scale precisely are some of the challenges at engineering level. Nanomaterials can be pyrogenic, thus production of a bio friendly material is a biological challenge. Social challenge such as ethics, public acceptance and human regulation is still a matter of concern which needs to be addressed before nanotechnology can enter the modern dental armamentarium [29].

## Conclusion

Nanotechnology is set to revolutionize clinical dental practice. It has been playing a significant role in changing phase of Prosthodontics. Recent studies have showed that, materials used in prosthodontics can be significantly improved after their scales were reduced and this transition change in prosthodontics will surely uplift the standard of care provided to the individuals by which the outcome of the treatment will become significantly favorable.

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