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REVIEW ARTICLE

Nanodentistry: The next big thing is small

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Abstract

Nanotechnology has revolutionized the field of dentistry with tremendous potential to provide a comprehensive oral health care using the nanomaterials, advanced clinical tools and devices. The new era of dentistry will encompass precisely regulated analgesia, tooth renaturalization, complete cure for hypersensitivity and rapid orthodontic treatment. Many novel nanotechnology products are on the way, and new treatment modalities are also proposed. Nanotechnology has increased the hope for better oral health care delivery and improved maintenance through the ongoing research in diagnosis, cure and prevention of oral diseases. This review article provides an insight about the importance and possible applications of nanotechnology in the field of dentistry.

Keywords: Dentifrobots, Nanocomposites, Nanodentistry, Nanorobots, Nanotechnology

Introduction

Most of the greatest inventions, have been the product of human curiosity and wonder. For many years, people around the world have been harnessing their eager through knowledge of science. The era of nanotechnology has become the greatest invention in the field of science and technology.[1] The budding nanotechnology has tremendous applications in health care leading to the evolution of nanomedicine (including nanodentistry). Dental nanorobotics is the most awaited and challenging application in nanodentistry. Nanotechnology has revolutionized the field of dentistry with tremendous potential to provide a comprehensive oral health care using the nanomaterials, advanced clinical tools and devices. Nanotechnology has increased the hope of better oral health care delivery and continuous maintenance through the ongoing research in diagnosis, cure and prevention of oral diseases.[2]

Nano is derived from the Greek word "*vavoς*" which means dwarf, by definition one nanometer (10^{-9}) or "one-billionth of a meter." It is engineering at the molecular scale. Nanotechnology helps us for better understanding of molecular structure and properties of materials.[3]

Background

The history of nanotechnology is still debatable. It holds a certain amount of doubt among the accepted opinions by scientists. There are different views among the scientists regarding the evolution of nanotechnology. Some scientists firmly believe it as, brand new form of science that evolved around the late 1980s or early 1990s. Although others holdback the history to the year 1959. Still other scientists believe that humans used nanotechnology perhaps even earlier in the ancient times, without any knowledge of the same in the form of steel, paintings and vulcanizing rubber.[4]

The vision of nanotechnology was again revisited by late Noble Physicist Richard Feynman by a talk given on "There's Plenty of Room at the Bottom," at an American Physical Society meeting at Caltech on December 29, 1959.[5] Feynman explained how single atom or molecule can be manipulated by the laws of physics that does not limit us for doing so but our lack of vision and methods are. He predicted that era would arrive soon where in matter can be manipulated at the atomic and molecular level.

The word nanotechnology was coined by Norio Taniguchi, and introduced by Prof. K. Eric Drexler. The term "nanodentistry" was first popularized in 2000 by research

scientist Robert Freitas.[6] The purpose of this article is to review the applications, current status of nanodentistry and to provide an insight about future, ethical and safety concerns of nanotechnology.

Nanostructures

Nanoparticles carry special properties such as chemical, optical, magnetic and electro-optical properties, which segregate them from individual molecules or bulk spices which lack these properties. These enhanced properties of the nanoparticles increase the mechanical properties like enhanced toughness, stiffness, transparency, increased scratch, abrasion, solvent and heat resistance and decreased gas permeability. The various nanoparticles are nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes, nanospheres, nanowires, nanobelts, nanorings, nanocapsules.[7]

Approaches to Nanotechnology

1. Bottom-up approach: This approach arranges smaller components into more complex assemblies.
2. Top- down approach: This approach creates smaller devices by using larger ones to direct their assembly.
3. Functional approach: This approach develops components of the desired functionality without much importance to their assembly or structure.
4. Speculative approach: This approach often takes a big-picture view of nanotechnology, with more emphasis on its societal implications than the details of how such inventions could actually be created.[3]

Application of Nanotechnology in Dentistry

Nanodentistry is an offshoot of nanomedicine. Application of nanomedicine to dentistry has led to the emergence of a branch of science called nanodentistry. Emergence of nanodentistry will aid in the maintenance of perfect oral health care through the use of nanomaterials, biotechnology, and nanorobotics. Application of nanodentistry [Table 1] can be categorized as "the top-down" approach and "the bottom up" approaches.[8]

Nanodentistry as Top-Down Approach

Salivary diagnostics powered by nanotechnologies

Saliva is a non-invasive and economical diagnostic aid in the diagnosis of oral diseases. This medium can be analyzed by the electromechanical biosensors which carry high sensitivity and specificity for the detection of oral diseases.[9]

Oral fluid nanosensor test (OFNASET)

The OFNASET is a portable, automated, user-friendly, integrated system that will detect the salivary proteins and nucleic acid targets in the saliva.[10]

Table 1: Applications of nanodentistry

Top-down approach	Bottom-up approach
Salivary diagnostics powered by nanotechnologies	Inducing anesthesia (Local anesthesia)
Nanocomposites	Hypersensitivity cure
Nanotechnology for glass ionomer cement	Tooth repair
Nano-ceramic technology	Nanorobotic dentifrice (dentifrobots)
Nanobond	Orthodontic nanorobots
Nanosolutions	Dental durability and cosmetics
Coating agents	Halitosis
Nanotechnology for impression materials	Nanotech floss
Nano-composite denture teeth	Photosensitizers and carriers
Implants	Diagnosis of oral cancer
Laser plasma application for periodontia	Treatment of oral cancer
Nano needles	
Nano bone replacement materials	
Nano bone fibers	
Nanoparticles as antimicrobial agents	
Nanotechnology based root-end sealant	

Nanotechnology for restorative dentistry

Nanocomposites

One of the most significant contributions to dentistry has been the development of resin - based composite technology. Nano-composite dental filling material is universal filling material which has superior mechanical properties for the restorations under occlusal load. Nanocomposites consist of nanofiller particles that are two types: Nanomeric (NM) and Nanoclusters (NCs). NM particles are monodisperse, nonaggregated and nonagglomerated silica nanoparticles. The average particle size is 5-75 nm, NCs particles - The primary particle size of this NC filler ranges from 2 to 20 nm.[11]

Advantages of nanocomposites: They have excellent mechanical properties such as hardness, strength and superior esthetic properties with high polish retention and lower polymerization shrinkage. These have very good handling properties that allow for optimal placement and contouring.[12]

Nano glass ionomer cement (GIC)

Nano glass ionomers are designed to meet the various requirements, same as other materials used in the mouth. Nanotechnology was used in the development to provide some value added features not typically associated with glass ionomer restorative materials.

By using bonded nanofillers and nanocluster fillers, along with FAS glass newer type of GIC was formulated using nanotechnology along with its fluoride releasing property. This

product meets a wide range of clinical indications ranging from Class I, II, V and core buildup. Nano GIC is an ideal restorative material for everyday dentistry. Advantages of this material are: superb polish, excellent esthetics, higher wear resistance, It is faster, easier to mix and dispense.[13]

Nano-ceramics

The Organically Modified Ceramic nano-particles comprise a polysiloxane backbone. These Nano-Ceramic particles can be best described as inorganic-organic hybrid particles where the inorganic part consisting of siloxane and the methacrylic organic part blends all the particles with resin matrix. The good resistance to microcrack propagation might be related to the strengthening effect of the nano-ceramic particles. Propagating cracks are either more often reflected or absorbed by the nano-ceramic particles.[14]

Nano bond (Bonding agents)

The new bonding agents are prepared from nano solutions which contain homogenous nanoparticles dispersed in the solution. Silica nanofillers are stable and do not cluster in the solution so provide the superior bond strength values. Nano interaction zone (NIZ - <300 nm) with minimal decalcification and almost no exposure to collagen fibers producing an insoluble calcium compound for a better bond less likely to deteriorate from enzymes contained in the mouth.[15]

Nanosolutions

These solutions have homogenously dispersed nanoparticles that extend their use in bonding agents. The new generation of bonding agents are one-step application. The homogeneously dispersed nanofillers provide the maximum bond strength and prevent particle settling.[12] Trade name: Adper O Single Bond Plus Adhesive Single Bond.

Coating agents

These agents contain light activated nanosized fillers which can be used as coating over the composite, glass inomer cements, jacket crowns and veneers. Incorporation of nanofillres provide superb polish on the restorations which prevents staining, increases abrasion and wear resistance.[16]

Nanotechnology for prosthetic dentistry

Impression materials

Impression materials Nanotech Elite H-D[13] from the company Zhermack is available with nanotechnology application. Here, nanofillers are perfectly blended with vinylpolysiloxanes, resulting in a unique addition siloxane impression material having added advantages of: Decreased viscosity, lesser voids in the impression, better handling properties, enhanced detail recording, high tear resistance, resistance to distortion, heat resistance.[1]

Nano-composite denture teeth

New type of denture tooth, fabricated of nanocomposite resin, has recently, been, developed as a highly polishable, stain and impact resistant material. It consists of uniformly dispersed nano-sized filler particles. It has advantages such as lively surface structure, available in different shades, matching the morphology of natural teeth, multifunctional use for all standard set-up techniques and extraordinary esthetics.[17]

Implants

Nanotechnology applied to implants can enhance the osseointegration, bone growth and ultimately increase the prognosis of the implant. These implants are surfaced with nanoscale deposits of hydroxyapatite and calcium phosphate, which create a suitable medium for osseointegration by activating the osteoblasts. These have proven to accomplish osseointegration by 150% thereby decreasing the length and number of appointments.[18]

Nanotechnology in surgical intervention

Inducing anesthesia

The new of revolutionary nanodentistry will have a colloidal suspension consisting of nanorobots measuring micron size with active analgesic properties. When these moving nanorobots are injected into patient's gingiva, they reach the pulp through gingival sulcus and dentinal tubules. These are controlled by the dentist to block all the sensation in that particular tooth. Once the procedures are completed, the dentist orders to restore all the sensation and to exit from the nerve pathways.[3] Nanorobotic analgesia provide greater patient comfort and decrease anxiety. They have increased selectively, controlled reversible analgesia with complete recovery with no side effects or complications.

Nanoneedles

These are used to execute the surgery on a single living cell and are nano-meter wide in dimension. Nanotweezers are also under development that will aid in cellular level surgeries in coming years.

Trade name: Sandvik Bioline, RK 91™ needles.[3]

Nanotechnology in periodontal therapy

Laser plasma application for periodontia

When TiO_2 particle sizes are reduced to nanoscale (20-50 nm diameter particles), and present on the human skin in the form of a gel-like emulsion, it has some interesting properties such that when irradiated with laser pulses, these particles can be optically broken down with accompanying effects like shock wave, micro-abrasion hard tissue, stimulation of collagen production and has been proven effective in a number of dental treatments including: Periodontal treatment, melanin pigment removal and incision of soft tissue without anesthesia.[19]

Nano bone fibers

These have a tensile strength 100 times that of steel (polyphosphazene nanofibers). These are assuming great interest in local drug delivery system because of their superior properties.[20]

Periodontal bone grafts
With both micro-porosity and nano-porosity, these have greater surface area compared to other synthetic bone grafting materials, allowing for ideal bone regeneration.[20]

Bone replacement materials
Nanotechnology is employed to produce "smart" material for periodontium, that will aid in the repair and regeneration of bone.[15] Hydroxyapatite nanoparticles used to repair bone defects are Ostim (Osartis GmdH, Germany), Vitoss (Orthovita, Inc. USA) and NanOSST (Angstrom, Medica, USA). Calcium phosphate enriched biomaterials have better handling properties, increased flow and blend well with host bone. These materials support the bone and cartilage growth.[3]

Nanomaterials for periodontal drug delivery
Nanomaterials such as nanotubes, hollow tubes and spheres, core-shell structure and nanocomposites have been widely experimented for local drug delivery system. These nanomaterials are made up of biodegradable polymer that allows the drug delivery to the site specific region of the tooth at regular intervals as these materials disintegrate. E.g., Arestin, in which tetracycline is incorporated into microspheres for drug delivery by local means to a periodontal pocket.[21]

Nanotechnology in preventive dentistry

Role in dental biofilms
Nanotechnology provides an insight on the interaction of microbial species in initiation and progression of the biofilm and also to understand the equilibrium between the demineralization and remineralization in the caries process using tools such as atomic force microscopy, which helps to detect the microbial induced demineralization.

New silver nanotechnology has been documented to be effective against biofilms. Silver has high affinity for negatively charged side groups sulfydryl, carboxyl, and phosphate on the cell membrane of the microbes. It targets multiple sites within the cell and interferes with various cellular pathways, cell wall and protein synthesis and function of the cell. It is mainly active against the microbes found in biofilms including *Escherichia coli, Staphylococcus pneumoniae, Staphylococcus aureus* and *Aspergillus niger*.[22]

Esthetics by ultrafine polishing
Polishing the teeth results in roughness, this provides medium for biofilm formation. Ultra-fine polishing of teeth leads to nanoscale roughness which is few in nanometers. It protects the teeth from cariogenic bacteria, which can be easily removed from these ultrafine polished surfaces, therefore prevent staining and lead to superior esthetics of the restorations.[15]

Nanotechnology microscope
The new developed deep probe detectors consisting of the electromagnetic spectrum will be available to screen the human body to reveal hidden matter such as, deep tumors and occult caries in teeth. This is known as Terahertz radiation, which lies in between light and radio waves in the spectrum.[23]

Nanotechnology in endodontics

Nanoparticles as antimicrobial agents
Nano particulates display higher antibacterial activity because of their polycationic or polyanionic nature, which extends their applications in numerous fields. Treatment of bacterial biofilms and wound healing gets the benefit from nanoparticles primarily because of their antimicrobial properties and biocompatibility. These disinfect the canal by removing the residual microbes in the canal and enhance the antibacterial action of the intra canal medicaments.[24]

Nanotechnology based root-end sealant
Nanomaterial enhanced retrofill polymers (NERPs) provide superior strength and contour well to the tooth structure. Bio aggregate, white nanoparticle ceramic cement is new-end filling material composed primarily of calcium silicate, calcium hydroxide, and hydroxyapatite. In *in vitro* study, NERP materials were also found to significantly reduce the micro-leakage, demonstrating their ability to seal effectively.[25]

Nanodentistry as Bottom–up Approach

Major tooth repair

Nanodentistry for major tooth repair may consist of growing the whole new teeth *in vitro* using genetic and tissue engineering and embedding them into the socket.[8]

Tooth renaturalization

Whole tooth renaturalization method may become popular and replace the conventional operative dental procedures. The patient may get benefited with replacement of the lost tooth with regeneration of the tissues.[8]

Hypersensitivity cure

Biological materials manufactured from nanotechnology can selectively occlude the dentinal tubules and provide fast and permanent cure to the patient. These can allay the anxiety and associated pain within minutes of application.[8,26]

Orthodontic nanorobots

Nanorobots may bring the direct changes in the periodontium including periodontal ligament and alveolar bone, leading to painless, rapid movement of the teeth within minutes to hours.[12]

Dental durability and cosmetics

Life of the tooth can be enhanced by replacing the enamel layers with biocompatible pure sapphire and diamond, which have hardness and strength 20-100 times more than that of natural enamel and ceramic.[27]

Nanorobotic dentifrice (dentifrobots)

Nanorobotic dentifrices, which may be available in mouthwash or toothpaste form, on contact with the tooth surface they scroll over the supragingival and subgingival surfaces, once in a day, removing the attached organic matter and debris on the tooth surface. These could detect the cariogenic bacteria in the biofilm with maintaining normal ecosystem of the oral cavity.[15]

Halitosis

Dentifrobots may prevent the oral malodor by interfering with the metabolism of bacteria.[15]

Nanotech floss

Ultra-thin, ultra-glide, completely non-shredding with excellent tensile strength. The unique nano-structure of dental tape allows for the addition of flavors, and delivery of medications.[3]

Photosensitizers and carriers

These reside on the surface of the target cell, when activated by UV light, they produce free oxygen radicals, which are harmful to the target cells.[3]

Diagnosis of oral Cancer

- Nanoelectromechanical systems
  Convert (Bio) chemical to electrical signal
- Cantilever array sensors
  Ultrasensitive mass detection technology:
  - Picogram (10-12) – Bacteria
  - Femtogram (10-15) – Virus
  - Attogram (10-18) – DNA
  - Multiplexing modality

  Sensing large numbers of different biochemical simultaneously in real time
  Application:
- Diagnosis of diabetes mellitus and cancer
- Detection of bacteria, fungi, and viruses.[3]

Treatment of oral cancer

- Nanomaterials for brachytherapy
  BrachySil™ (Sivida, Australia) delivers 32P, Clinical trial
- Drug delivery across the blood-brain barrier
  More effective treatment of brain tumors, Alzheimer's, Parkinson's in development
- Nanovectors for gene therapy
  Non-viral gene delivery systems.[3]

Challenges Faced by Nanodentistry

- Requires proper assembling of the molecules to build a functional unit.
- Financial constraints for mass production of nanorobots
- Biocompatibility
- Difficulty in coordinating the activities of nanosized Nanorobots
- Public acceptance is questionable
- Ethics and regulations have to be formulated
- Human safety, issue requires further research.[3]

Hazards of Nanotechnology

Nanotechnology, the emerging science, provides solutions to many problems of mankind. However, nanotechnology may not be flawless. "The smaller the particles, the more toxic they become," tests have shown that nanotechnology can function as venom to the communities we live in and nanoparticles are known to biomagnify in animal organs. Scientists are also concerned about soil and plant life. Nanoparticles can cause lung injuries. By balancing its risk and benefit, we can maximize applications in medicine without harming the public health and environment.[28]

Conclusion

"How very small the very great are" thus, the greatness of this technology lies in its minuteness, i.e., Nano-ness. Recent developments of nanoparticles and nanotubes in operative dentistry, endodontics, periodontal management, will play a growing role in the enhancement of dental industry. Ongoing research in restorative materials and treatment approaches will increase the quality of dental care in the future.

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