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Review Article

Nanotechnology in dentistry: Present and future

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Abstract:

Nanotechnology is the manipulation of matter on the molecular and atomic levels. It has the potential to bring enormous changes into the fields of medicine and dentistry. A day may soon come when nanodentistry will succeed in maintaining near-perfect oral health through the aid of nanorobotics, nanomaterials and biotechnology. However, as with all developments, it may also pose a risk for misuse. Time, economical and technical resources, and human needs will determine the direction this revolutionizing development may take. This article reviews the current status and the potential clinical applications of nanotechnology, nanaomedicine and nanodentistry.

Key Words: Nanodentistry, nanomaterials, nanorobots, nano-technology

Introduction

The word nano originates from the Greek word "dwarf". The concept of nanotechnology was first elaborated in 1959 by Richard Feynman, a Nobel Prize winning physicist, in a lecture titled, "There's plenty of room at the bottom". He ended the lecture concluding "this is a development which I think cannot be avoided".[1] Since then, nanotechnology has found use in a myriad of applications including dental diagnosis, material and therapeutics. A day may soon come when nanodentistry will succeed in maintaining near-perfect oral health through the aid of nanorobotics, nanomaterials andbiotechnology.[2]

The purpose of this article is to review nanotechnology, nanaomedicine and nanodentistry in the present scenario, as well as in the time to come.

Nanomaterials

Nanomaterials are those materials with components less than 100 nm in at least one dimension. These may include atoms clusters, grains, fibers, films, nanoholes, and composites from these combinations. Nanomaterials in one dimension are termed as sheets, in two dimensions as nanowires and nanotubes, and as quantum dots in three dimensions.[3]

Nanomaterial properties

Nanomaterial properties vary majorly from other materials due to two reasons: the increase in surface area and quantum effects. Nanoparticles due to their small size have a much increased surface area per unit mass compared to bigger particles. In addition, quantum effects become more dominant at the nanoscale. All properties, including electrical, optical and magnetic ones, arealtered.[4]

Nanotechnology

Prof Keric E Dexler, an expertin the field of nanotechnology, coined the term nanotechnology. It is the manipulation of matter on the molecular and atomic levels.[3,4]

Nanotechnology has applications in many fields like[5]

- Medicine
  - Diagnostics
  - Drug delivery
  - Tissue engineering
- Chemistry and environment
  - Catalysis
  - Filtration
- Energy
  - Reduction of energy consumption
  - Increasing the efficiency of energy production
  - Recycling of batteries
- Information and communication
  - Novel semiconductor devices
  - Novel optoelectronic devices
  - Displays

- Quantum Computers
- Heavy Industry
  - Aerospace
  - Refineries
  - Vehicle manufacturers
  - Consumer goods
  - Foods.

Nanomedicine

Nanaomedicine is the science of preventing, diagnosing, and treating disease and preserving and improving human health, using nanosized particles.[6]

Types of nanotechnologies in nanomedicine

They can be generally divided into three potent molecular technologies:

- Nanoscale materials and devices to be applied in advanced diagnostics and biosensors, targeted drug delivery, and smart drugs
- Molecular medicine through genomics, proteomics, artificial biobotics (microbial robots)
- Molecular machines and medical nanorobots aid inimmediate microbial diagnosis and treatment, and enhancement of physiological functions.[5]

Nanorobots

Nanorobots have a diameter of about 0.5–3 microns and made of components sized from 1–100 nanometers. Carbon will be the primary component in the form of diamond or fullerene. Nanorobots would respond to definite programs enabling clinicians to execute accurate procedures at the cellular and molecular level. Nanorobots may also find use in the field of gerontology, with diverse applications in pharmaceutics, diagnostics, dental therapy, in reversal of atherosclerotic damage, enhancing lung function, aiding natural immunity, repairing brain injury, modifying cellular DNA sequences, and repairing cellular damage.[5]

Nanosensors

Nanosensors have been used for military application in identifying airborne harmful materials and weapons of chemical warfare and to identify drugs and other substances in expired air.[5]

Implantable materials[7]

These materials can be applied in various fields:

- Tissue healing and substitution
- Coatings for implants
- Tissue regeneration scaffolds
- Implant materials
- Osseous repair
- Bioresorbable materials
- Smart materials
- Diagnostic and therapeutic devices
- Sensory aids
- Cochlear and retinal implants.

Nanophase materials

Nanophase materials are promising materials for various bio-applications as human tissues themselves are composed of nanometer components.

- Nanophase hydroxy apatite

Osteoblasticadhesion and growth are vastly increased on nanophasehydroxy apatite (HA) than on traditional HA. In addition, nanophase alumina and titania also show similar features. Hydroxy apatite nanoparticles used to treat bone defects are:

- Ostim HA (Osartis GmbH, Germany)
- Vitosso (Orthovita, Inc) HA + TCP (tricalcium phosphate)
- NanOSSTM HA (Angstrom Medica).[8]

- Nanophase carbon

Carbon nano fibers have extra ordinary conjectural mechanical properties in addition to nanoscale dimensions like natural HA; these features support its proposals a maxillofacial implant material.[8]

Nanodentistry

Approaches to nanodentistry

Bottom-up approaches[9]

- Assembly of small components into compound structures.

Top-down approaches[10]

- Creation of small structures by using bigger ones in guiding their assembly

A. DENTAL NANOROBOTICS - Bottom-Up Approach

Local Nanoanaesthesia

A colloidal suspension containing millions of anesthetic dental nanorobots would be used to induce local anesthesia. Deposited on the gingival tissue, the nanorobots would reach the dentin and move toward the pulp via the dentinal tubules, guided by chemical differentials, temperature gradients, and positional steering by a nanocomputer under the control of the dentist. On reaching the pulp, the analgesic robots may close down all sensation in the tooth. When the treatment procedure has been concluded, the nanorobots may be ordered to re-establish all sensations and to exit from the tooth. This technique is advantageous as it reduces apprehension and is fast and totally reversible.[1]

Hypersensitivity cure

Dentin hypersensitivity is another area where dental nanorobots may find their use.

Nanorobots, using local organic materials, could result in effective occlusion of particular tubules, resulting in rapid and stabletreatment.[1]

Tooth Repositioning

All the periodontal tissues, namely the gingiva, periodontal ligament, cementum and alveolar bone, may be directed by orthodontic nanorobots leading to swift and painfreecorrective movements[11]

Nanorobotic dentifrice (Dentifrobots)

Toothpastes or mouthwashes could contain the dentifrobots which would then survey all gingival surfaces regularly. They would also break down harmful materials into harmless substances and undertake constant calculus removal.[1]

Dental durability and cosmetics

Changing the superficial enamel layer with materials like sapphire[12] or diamond may enhance the toughness and appearance of teeth as these materials have 20-100 times the hardness of enamel. However, diamond and sapphire are brittle, but can be made tougher by their inclusion as part of a nanostructured composite.[13]

Nanodiagnostics (Photosensitizers and carriers)

Intracellular imaging using innately fluorescent proteins that enable various biochemical reactions to be studied directly has already become a likely prospect. Quantum dots may also play the role of a photosenstizer and carrier. They attach the antibody to the target cell and on stimulation by UV light, result in the formation of reactive oxygen species which destroy the target cells.6 another role of nanotechnology may lie in overcoming some drawbacks of biochip technology.[14]

Therapeutic aid in oral diseases

Nanotherapeutics / Drug delivery

Nanotechnology will eliminate the solubility problems, lead to a reduction in the dosage of drug and reduce the adverse effects.[6,15] This may be utilized in treating Alzheimer's disease, Parkinson's disease, brain disorders etc. It may also lead to increased bioavailability.[16]

Gene Therapy

This technique prevents or treats genetic diseases, by correcting faulty genes that lead to disease development by repairing or replacing them. Gene delivery systems may be broadly categorized into three types: viral vectors, nonviral vectors, and the direct innoculation of genes into tissues (gene guns).[17]

Diagnosis of oral cancer[18]

- Nanoscale cantilevers: Elastic beams used to attach with cancer linked molecules.
- Nanopores: Small holes that enable DNA passahe one strand at a time, thus making DNA sequencing highly efficient.
- Nanotubes: Carbon rods that can detect affected genes and also localize their location.
- Quantum dots: These glow very brightly in UV light. They attach to proteinsassociated with cancer cells, thus localizing tumors.

Treatment of oral cancer[18]

- Options include the following:
- Nanomaterials for brachy therapy
- BrachySilTM delivers 32P
- Nanovectors for gene therapy
- Nonviral gene delivery systems

A nanoshellis a tiny beadlike structure with superficial metal layers which may imbibe selective wavelengths of radiations and lead to large amounts of heat production. This results in specific devastation of the tumor cells, sparing the normal cells. Dendrimers possess certain characteristics like high degree of branching, multivalency, rotund shape and well defined molecular weight, which makes these an ideal candidate for cancer therapy.[19]

B. DENTAL NANOMATERIALS - anodentistry as top-down approach[20]

Nanocomposites

Nanotechnology has revolutionarized restorative dentistry by providing nanofillers.These filler particles are very minute, higher proportions can be achieved, and result indistinctive physical, mechanical, and optical properties.[21]

Nanocomposites, defined by filler-particle sizes of ≤100 nm, can broadly be divided into nanohybridand nanofilled resin-based composites. Nanocomposites have comparable or better finishing, polishing ability, shade matching, flexural strength and hardness than conventional composites. Beun *et al.* compared the physical properties of nanofilled, universal hybrid and microfilled composites, and observed a higher elastic modulus with the nanofilled RBC than most of the hybrids tested.[22]

One nanocomposite system (Premise, Kerr/ Sybron, Orange, CA) has three different types of fillers: nonagglomerated "discrete" silica nanoparticles, barium glass, and prepolymerized filler.[5]

Nanoproducts Corporation has produced nonagglomerated coatings to make nanocomposites. The nanofiller used includes an aluminosilicate powder with a mean particle size of 80 nm and a 1:4 M ratio of alumina to silica and a refractive index of 1.508.

Trade name: Filtek Supreme universal restorative pure nano[5]

Advantages:[3,5,11]

- Increased hardness.
- Improved flexural strength, toughness and translucency.
- Decreased polymerization shrinkage (50%).
- Exceptional handling properties.
- High polish retention
- Higher translucency giving it more lifelike appearance

Nanosolution (Nanoadhesives)

Nanosolutions are constituted by dispersible nanoparticles, which are then used as a component in bonding agents. They lead toa homogenous and perfectly mixed adhesive consistently.[23]

Advantages:[24,25]

- Higher dentine and enamel bond strength

- High stress absorption
- Longer shelf life
- Durable marginal seal
- No separate etching required
- Fluoride release

Trade name: Adper Single Bond Plus Adhesive Single Bond

Nano Light-curing glass ionomer restorative[11]

This blends Nanotechnology initially developed for Filtek™ Supreme Universal Restorative with fluoralumino silicate technology.

Advantages:

1. Excellent polish.
2. Superb esthetics.
3. Enhanced wear resistance

Clinical Indications:

- Primary teeth restoration.
- Transitional restoration.
- Small Class I restoration.
- Sandwich restoration.
- Class III and V restoration.
- Core build-up.

Impression materials

Traditional vinylpolysiloxanes have incorporated nanofillers, which produce a distinctive material with improved flow, enhanced hydrophilic properties and superior detail precision.[23]

Trade name: Nano Tech Elite H-D+

Nano-composite denture teeth

Conventional denture teeth have their own inherent disadvantage. Porcelain is highly wear resistant, but is brittle, lacks bonding ability to the denture base, and is not easy to polish. Acrylic on the other hand is to adjust, but undergo undue wear. Nanocomposite denture teeth are made of Polymethylmethacrylate (PMMA) and homogeneously distributed nanofillers.[20]

Advantages:

- Excellent polishing ability and stain-resistant
- Superb esthetics
- Enhanced wear resistance and surface hardness

Nanoencapsulation

Specifically targeted release systems have been developed by South West Research Institute (SWRI). These include nanocapsulesin the form of new vaccines, antibiotics, and delivery of drugs with fewer adverse effects. In 2003, Osaka University in Japan made possible the targeted delivery of genes and drugs to human liver. In the time to come, dedicated nanoparticles might be developed to focus on oral tissues.[11,25]

SWRI has developed several other products as well:

- Protecting outfit and mask, incorporating antipathogenic nano-emulsions and nano-particles
- Medical appendage for immediatecure: These may include various types of dressings.
- Bone targeting nanocarriers: These are materials based on calcium phosphate which flow and integrate with natural bone easily.[25]

Dentifrices

These are mainly made up of nanosized hydroxyapatite molecules. They will result in protectiveshell on tooth surface and may even repairdamaged areas. Microbritedentifrice hasmicrohydrin(1-5 nanometers) which breaks down the organic food particles.[26]

Laser Plasma Application for periodontia

Application of nanosizedtitania particle emulsion on human skin followed by laser irradiation, leads to the disintegration of the particles along with other results like:

- Shock waves
- Microabrasionof hard tissues
- Stimulus to produce collagen[20]

Clinical applications:

1. Periodontal therapy
2. Melanin removal
3. Soft tissue incision(without anesthesia)
4. Cavity preparation- Enamel and dentin cutting

Bone replacement materials

Bone is a natural nanocompositemade up of organic compounds (mainly collagen) toughened with inorganic compounds like hydroxyapatite. This architecture should be simulated for orthopedic and dental use. Also, with the reduction in particle size, the surface area increases manifold. This rule has been utilized by Nano-Bone®.[27]

Characteristics of bone graft materials are:

- Osteoinductive
- Completely synthetic
- Non-sintered
- Extremely porous
- Nano-structured
- Degradation by osteoclasts
- Excellent processability
- No products in ionic solution

Chen et al. have tried to create dental enamel by using extremely structured calcium hydroxyapatite crystals prearranged in a parallelpattern.[28]

Various HA nanoparticles used in repairing osseous defects are;

- Ostim ® HA.
- VITOSS ® HA+ TCP.
- NanOssTM HA

Materials for induction of osseous growth:

Conventional calcium sulphate has been used to plug small osseous defects like in post extraction sockets and periodontal bone defects and in addition to bone graft material. A new calcium sulphate based composite has been developed by Dr Ricci, Bone Gen –TR. Itbreaks down more slowly and regenerates bone more effectively.[3]

Prosthetic Implants

Nanotechnology would aid in the development of surfaces with definite topography and chemical composition leading to predictable tissue-integration. Tissue differentiation into definite lineage will accurately determine the nature of peri-implant tissues. In addition, antibiotics or growth factors may be incorporated as CaP coating is placed on Ti implants.[29]

eg: Nanotite™ Nano-Coated Implant.

Radiopacity

Nanoparticles may be incorporated in materials and instruments to achieve radiopacity without affecting properties or the risk of toxicity and carcinogenicity associated with heavy metals.[25]

Orthodontic wires:

Orthodontic wires may be drawn from a novel stainless steel material, Sandirk Nanoflex. This has the advantage of very high strength along with excellent deformability, corrosion resistance and fine surface finish.[25]

Nanoneedles

Nano-structured stainless steel crystals have been used to manufacture suture needles. (SandvikBioline, RK 91 needles, AB Sandvik, Sweden). Plans to make nanotweezers are also under way, which may enable cell surgery feasible.[5,11]

Nano sterilizing solution:

A new sterilizing solution following nanoemulsion concept has been developed by Gandly Enterprises Inc Florida. Nanosized oil droplets attackand destroy the pathogens.[24]

E.g.: Eco Tru Disinfectant.

Advantages:

- Broad spectrum
- Hypoallergic
- Noncoroding
- Does not stain fabric
- Require no protective clothing
- Environment friendly
- Compatible with various impression materials.

C. REGENERATIVE NANOTECHNOLOGY - Bio-Mimicry

Dentition renaturalization

This technique may revolutionarize cosmetic dentistry. Initially, old amalgams restorations may be removed and the teeth remodeled with natural materials. This may be followed by complete coronalrenaturalization procedures in which all previous procedures may be undone and all the teeth remanufactured to become identical to natural teeth.[27]

Dentition replacement therapy (Major tooth repair)

Nanotechology may utilize genetic engineering, tissue engineering and tissue regeneration initially, followed by growing whole new teeth in vitro and their installation. Eventually, production and installation of an autologous tooth may become possible in a single office visit.[30]

Challenges faced by Nanotechnology

- Precise positioning and manufacture of nanoscale parts.
- Cost-effective nanorobot mass manufacturing methods.
- Synchronization of numerous independent nanorobots.
- Biocompatibility concern.
- Financing and tactical concerns.
- Inadequate assimilation of clinical research.
- Social issues of public acceptance, ethics, regulation and human safety.[5,11]

Future

Nanotechnology is foreseen to change health care in a fundamental way. The Foresight Institute has offered the $250,000 Feynman Grand Prize to the first researcher or researchers who develop two devices: a basic nanorobot and a nanocomputer. Christine Peterson, president of the Foresight Institute, estimates that the prize will be claimed between 10 and 30 years from now. Because the initial nanodevices will be basic, prototypical units, commercial applications will follow years later.

Conclusion

Nanotechnology will bring enormous changes into the fields of medicine and dentistry. However, as with all developments, it may also pose a risk for misuse and abuse. Time, newer developments, economical and technical resources, and human needs will determine which of the applications are realized first.

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