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Review Article

Nanotechnology in interdisciplinary dentistry

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ABSTRACT

Nanotechnology has toppled the world, revolutionizing almost every field such as biology, physics, chemistry, mathematics, engineering, industry, medicine, pharmacology, dentistry, and many more. The "Maxwell's demons" as the nanoparticles were called earlier, have helped humankind in achieving profound effects by manipulation of the materials in the nanoscale. The concept of nanotechnology has left almost no field untouched. Ever since the advent of the term "nanodentistry" by R.A Freitas Jr. in the year 2000, the applications of nanotechnology have been incorporated in the field of dentistry, striving its best to develop better diagnostic, treatment, and maintenance systems in oral health care. This article discusses the various applications of nanodentistry in an interdisciplinary approach.

Keywords: Nanotechnology, Nanodentistry, Nanoparticles, Nanodiagnostics

INTRODUCTION

Nanotechnology, also called molecular manufacturing, is an interdisciplinary science concerning the tiniest of particles in the molecular inter and intracellular level. It has revolutionized various fields such as engineering, physics, chemistry, biology, material science, medicine, and information technology, thereby transporting humanity to a new era. Its tremendous evolvement has found diverse applications in health care like nanoimaging through the use of biosensors, nanoparticles and capsules for drug delivery, vaccination, and gene vehicles for chemotherapy. These nanosize particles interact easily with the other molecules and hence have found a myriad of applications to our advantage. In dentistry, nanotechnology has been explored in material science, restorations, oral surgery, diagnostics, and drugs. Nevertheless, its applications are limited in practicality due to engineering, biological, and social challenges warranting an in-depth research and clinical studies in the field of nanotechnology.[1]

"***Miniature Marvels That Can Move Mountains***"

Awakening of a new era

The concept of nanotechnology was elaborated way back in 1959 at the Annual Meeting of the American Physical Society by the Nobel laureate and the "Great Explainer," Richard Feynman, in a lecture titled, "There's plenty of room at the bottom. An invitation to enter a new field of Physics." He sowed the seed of the concept of nanotechnology which awakened the interest for further research in the field.

In the year 2000, R.A. Freitas Jr. coined the term "nanodentistry." He envisioned the prospective applications and developments of nanoscience in various aspects of dentistry such as nanorobotics in inducing anesthesia, tooth repair, treatment of dental hypersensitivity, dental esthetics, tooth repositioning, and periodontal diseases.[2]

A peek into the nano specks

Nanomaterials are components that are <100 nm (1 nm = 10^{-9} m) at least in one dimension, with increased surface area per unit mass and more dominant quantum effects. They constitute atom clusters, grains, fibers, films, nanoholes, nanopores, nanotubes, nanoshells, dendrimers, etc.[3]

The principle of nanotechnology involves bottom-up and top-down approach, which is depicted by a simple illustration as follows:

Aids in nanodentistry

The potent technologies that serve as aids to nanodentistry are as follows:

1. Nanomaterials in advanced diagnostics, biosensors, targeted drug delivery, and smart drugs;

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2. Genomics, proteomics, and biobotics (artificial nanorobots);
3. Future prospects include theranostics, tissue engineering, magnetofection, regenerative medicine, and gene therapy.

Nanodentistry – a promising Dexter

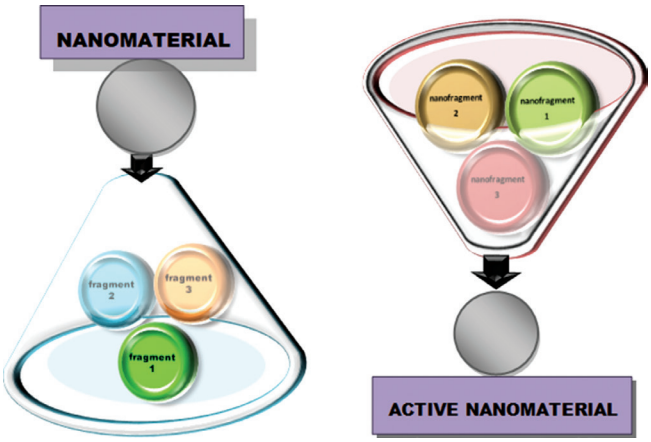
Nanodentistry has a vast area of application in various streams. It has perfected and attempts to create new strides in diagnosis and treatment of oral diseases for the betterment of humanity.

Nanotechnology has conquered the conventional techniques in local anesthesia, drug delivery, restorative materials, cosmetic dentistry – tooth durability and esthetics, treatment of hypersensitivity, correction of malaligned teeth, prosthesis – dentures and implant materials, impression materials, nano surgical instruments – needle and tweezers, dentifrices, LASER plasma, bone substitutes, sterilization products, tissue engineering, digital imaging, screening, and diagnosis of oral tumors.[4]

Nanodentistry – an interdisciplinary kaleidoscope

Nanotechnology in oral medicine and radiology

A major breakthrough that paves way to never exhausting advancements in nanomedicine is nanoindentation, atomic force microscopy, and scanning tunnel microscopy. They demonstrate resolution in the order of fractions of a nanometer and also produces topographical three-dimensional images in real space. It meets the demands of early, rapid, sensitive, and economically feasible diagnosis, especially inflamed tissues and tumor, which poses major challenges in oral medicine and radiology. The various nanostructures employed in nanodiagnostics are quantum dots, nanoscale cantilevers, nanopores, nanotubes, and gold nanoparticles. They have opened up the scope for a new specialist field called theranostics by serving diagnostic and therapeutic purposes simultaneously.



TOP-DOWN - Breaking of the large materials into smaller nanofragments

BOTTOM-UP - Integration of smaller fragments into the active nanomaterial

Nanotechnology in periodontics

Quantum dots (QDs) coupled with immunofluorescence helps in precisely labeling specific periodontal pathogens aiding in clear diagnosis of periodontal diseases. Lead-free and cadmium-free quantum dots are used in periodontal therapy to enhance healing of inflamed tissues. Their photosensitizing property has profound applications in cancer treatment, tumor localization, margin detection, identification of important adjacent structures, mapping of sentinel lymph nodes, and detection of micrometastases.[5]

Nanotechnology in plethora of oral hygiene aids to combat dental caries and dental hypersensitivity

Biofilms and irreversible loss of tooth structure due to dental caries have always been the culprit in interruption of any dental procedure and take a toll on the success of the treatment. The incorporation of nanotechnology in dentifrices has paved way for novel strides in controlling bacterial biofilms and preventing dental caries by remineralization of early carious lesions and in desensitization in case of abraded teeth.[6]

Nanocarbonate apatite has proven to be very efficacious desensitizing dentifrice. Hydroxyapatite nanocrystals are being explored extensively in various applications from tooth remineralization to bone implants. The efficacy of silver and triclosan loaded nanoparticles in oral hygiene aids is well known. These substances instilled in the form of dentifrobots/artificial nanorobots in dentifrices and mouthwashes effectively maintain oral health.

Nanocomposite coating over tooth, dentures, and implant surfaces have proven to render the surfaces plaque free and easily cleansable. Calcium apatite nanocomplexes coupled with proteins like casein phosphopeptide help to reduce adherence of bacteria on the tooth surface by disrupting the intercellular plaque matrix in bacterial biofilms.[4]

Nanotechnology in restorative dentistry

Nanotechnology has been incorporated in dental restorative techniques that result in enhanced esthetics, mechanical properties, and polymerization kinetics. Nanofillers are added in the manufacture of dental composites, ionomer cements, endodontic sealers, and remineralization agents. Further research aims at reducing the nanomeric particle size than the wavelength of visible light to achieve highly translucent material, high surface area to volume ratio, and molecular interaction. Embedded quantum dots in dental resins can tune their emission color.

Nanotechnology in orthodontics

In orthodontics, nanocomposites and nanoionomers (consisting of nanoagglomerated particles and nanoclusters (made up of fluoroaluminosilicate glass and zirconia) improve chemical adhesion, improve bond strength, mechanical properties, provide good marginal seal, and also have an advantage of fluoride release when used as adhesive.[3]

Nanotechnology in endodontics

Bioceramic-based nanoparticles incorporated into endodontic sealers have revolutionized obturation by gaining access into irregular dentinal surface. Quaternary ammonium polyethyleneimine (QPEI) nanoparticles in the same provides excellent antimicrobial properties.

Nanotechnology in oral and maxillofacial surgery

Bone grafting procedures face many limitations such as limited supply, variable resorption, high failure rates, and persistent pain. Application of nanotechnology in tissue engineering and stem cell research has overcome various challenges and breaks the barriers of conventional methods in the treatment of orofacial fractures, bone augmentation, cartilage regeneration of TMJ, pulp repair, periodontal regeneration, and implant osseointegration.[7,8]

Nanofibers which are similar to the structure of collagen and hydroxyapatite crystals in bone have been developed for bone tissue engineering. Nanoparticles can also enhance the osteoconductive property and biocompatibility of biodegradable polymer and ceramic materials used as grafts. They act as 3D scaffold matrix for new bone formation. The most recent and superior bone grafts are nano hydroxyapatite reinforced with chitosan or titanium because they demonstrate good cellular response and superior biocompatibility when compared to other bone grafts. A synthetic precursor of hydroxyapatite called octacalcium phosphate is found to increase the osteoblastic activity.[9]

Nano-LIPUS (low-intensity pulsed ultrasound) devices are effective in stimulating fibroblast growth factors and enhance wound healing, bone growth into titanium porous coated implants, and in distraction osteogenesis.[10] Nanostructured coatings of hydroxyapatite and nanoporous alumina are said to improve the biointegrative properties of dental implants. Further research is being carried out in inventing chip design that fits precisely into the patients' oral cavity.

Nanotechnology in dental material science

Nanoceramic composite materials with encapsulated zinc oxide and walled carbon nanotubes in alginate polymer matrix show excellent antibacterial activity. The most prevalent nanomaterials used in dentistry today are the nanofilled and nanohybrid composite restorative materials. They have been proven to enhance the handling characteristics and physiomechanical properties to a great extent. More recently, stabilized nanomers of radiopaque materials such as zirconia, ytterbium fluoride, and barium sulfate have been incorporated in dental materials. Zirconia nanoparticles (of <50 nm) stabilized with carboxylate and silica nanoclusters have been used as fillers in dental adhesives, composites, and novel resin-modified glass ionomers (RMGIs). Weakly agglomerated nanoparticles of tantalum oxide and silica have been incorporated into experimental dental adhesives. Experimental methacrylate and epoxy functionalized nanocomposites based on silsesquioxane cores for dental applications are underway to revolutionize restorative science.

Nanotechnology in maxillofacial prosthodontics

The incorporation of silver nanoparticles in prosthetic materials such as polymethylmethacrylate and silicone has proven in effective antimicrobial activity. The mechanical properties such as impact strength and physical properties such as color stability can be enhanced by the incorporation of titanium dioxide and cerium dioxide nanoparticles. Thus, nanotechnology has transformed the face of dental and maxillofacial prosthodontics at a root level.[11]

Nanotechnology in drug delivery systems and immunology

Nanobased gene therapy, nano drugs, and magnetic drug targeting (MDT) are the novel areas of focus, trending on local drug delivery systems and chemotherapy. The novel coronavirus disease labeled by the World Health Organization (WHO) as COVID-19 has opened a worldwide platform for the application of nanotechnology in the control of the disease. The nanofiber-based facial respirators, nanomedicine, and nanodiagnostic aids such as chemiluminescence immunoassays and colloidal gold nanoparticle probe-based immunoassays have gained interest in rapid and effective control of the disease. Extensive research is being conducted to win the race against time in flattening the epidemic curve and develop vaccines to battle the disease.[12]

CONCLUSION

Nanodentistry is a strong promising tool in revolutionizing oral health care and esthetics. However, the new prospects are associated with debates on biocompatibility and toxicity, social risks, and ethical questions involved, especially when mass production is anticipated. The cell type is also a major determinant, as specific targeting, cellular entry, subcellular

targeting, and modulation of cellular process repair are all yet to be explored in depth.

Therefore, it is important to fully understand the qualitative and quantitative response of human cells to artificial nanoparticles. Expertise in precise positioning and techniques is another critical factor that determines the success of nanodentistry.[13] The applications of nanorobotics and nanostructured particles have a long way to go and extensive research is underway to create novel advancements in the era of molecular therapeutics.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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