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Review Article

Nanodentistry: Is just a fiction or future

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ABSTRACT

Nanotechnology creates incredibly useful structures from individual atoms or molecules, which provides a new alternative and a possibly superior approach for the identification of oral health related problems and also in designing of more biocompatible dental materials with better properties and anticaries potential. Nanodentistry is striving its best to apply new advances in dental practice. The present article discusses the use of nanotechnology in dentistry and also the latest innovations in oral health care, nanoincorporated products, and issues of patient safety and occupational health.

1. Introduction

Human civilization and human science always have a progress and always will progress. If we do not seek new vistas outward, we investigate inward. Either we will introspect and discover the Universe within ourselves, or we try to delve deeper into the mysteries of the living cells, or molecules, or even single atoms. As we learn more, we realize that sometimes the most profound effects will be achieved by going smaller and smaller down to the nanoscale. Instead of preparing medicines, and hoping that they will have a selective effect, we are thinking and researching methods that have an absolutely precise effect.

The Era of Nanotechnology has dawned.[1] It will change science, medicine and possibly dentistry. These technologies are largely in conceptual stage, but we can sense that soon products out of it will be present in usable form everywhere. Nanotechnology is bringing a revolution in the world of science. It works at the level of atoms and molecules and manipulates them according to the need. The word "nano" is derived from a Greek word "nannos" which means "dwarf." Nanometer means one millionth of a meter (10^{-9} meter).[2] Literature has given two concepts of nanotechnology, i.e., broad and narrow concepts. Broad concept signifies a technology smaller than microtechnology, while the narrow concept programs and manipulates matter with molecular precision.[3]

2. Developmental history of nanotechnology

As early as 1867, James Clerk Maxwell proposed a revolutionary concept of nanotechnology. When the whole world was looking at making things bigger and bigger, he envisaged submicroscopic machines with the ability to handle individual

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atoms and molecules. He called these Maxwell's demons, which were what we call 'Nanorobots' these days. The term nanotechnology was given/introduced by Prof. Kerie E. Drexler. In the early 20th century, Richard Zsigmondy brought about the concept of nanomaterials.[4] In 1959, Richard P. Feynman, the Nobel Laureate said that his friend, Albert R. Hibbshad suggested an interesting possibility for extremely small machines.[5] Albert R. Hibbshad presented a landmark lecture entitled, ''There is plenty of room at the bottom'' at the annual meeting of the American Physical Society. This lecture would lay the foundations of all the basic concepts of Nanotechnology. He talked about future possibility of creating materials and devices at the atomic or molecular level.[6] He also suggested that nanomachines, nanorobots and nanodevices could be used to produce atomically precise microscopic instrumentation and production tools.[7] Though at that time, these were merely ideas, but they set about a new way of thinking. Scientists realized that profound effects could be achieved, by manipulating matter at atomic and molecular levels.

R.A. Freitas Jr., in the year 2000, coined the term ''nanodentistry''. He developed visions using nanorobots for orthodontics, dentition regeneration, nanomaterials, and robots in dentifrices–dentifrobots. Although most of his ideas were and remain science fiction, these ideas are gradually being realized into practice. Today many applications of nanoscale technology are known and used in the field of dentistry.[8]

3. Nanomaterials

Nanomaterials can be classified as zero-dimensional, one-dimensional, two-dimensional, and three-dimensional.[9] Different types of nanoparticles include nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes (bucky-balls), nanospheres, nanowires, nanobelts, nanorings, nanocap, and many more.[10]

Feynman discussed about manipulating individual atoms to produce new small structures with different properties from parent atoms.[11] Nanomaterials have small size, larger surface area, high surface energy, large proportion of surface atoms and so on; owing to these, it has some different properties such as small size effect, quantum size effect, quantum tunneling effect, and surface effect.[12]

Three approaches for the synthesis of nanoparticles are top-down approach, bottom-up approach and functional approach.[13] In top-down approach, particles are synthesized in the conventional manner and made smaller by grinding or milling. While in the bottom-up approach, nanoparticles are synthesized by direct molecular synthesis and bonding, i.e., they are synthesized from molecular level.[7] The functional approach, on the other hand, does not give importance to the method of production of a nanoparticle; rather, it emphasizes on production of nanoparticle with a specific use.[13]

4. Applications of nanotechnology

No field will remain untouched by nanotechnology. It will affect the fields of biology, chemistry, physics, mathematics, engineering, industry, medicine, dentistry, and many more. In industries, it has been used in steel-making process, and vulcanizing rubber.

The nanotechnology is progressing so fast that it will not be wrong to called it as Magic Bullet as said by the Nobelist Paul Erlich. Various nanosystems such as solar energy collection, hydrogen production, glues, paints and lubricants, new forms of computer memory, and printable electronic circuits, and various optical components are emerging as new achievements of nanotechnology.[14] Nanomedicine and nanodentistry are also subfields of nanotechnology.

5. Nanomedicine

Nanomedicine helps in prevention, diagnosis, and treatment of various diseases. Nanorobots can be applied in chemotherapy to combat cancer to precisely deliver exact amount of chemotherapeutic agents directly to the target cells. This would be a more efficient mechanism, with much reduced side effects as normal cells would be spared. Such drug delivery nanorobots were called ''Pharmacytes'' by R.A. Freitas in 2000. Medical nanorobots augment the immune system by detecting and deactivating the harmful bacteria, viruses, and other pathogens.[15] Nanoscale-structured materials, biotechnology, genetic engineering, and complex molecular machine systems help in preserving and improving human health.[6]

Nanotechnology can provide newer, more potent formulations, which will have some decreased side effects. Drugs can be delivered with the help of nanorobots, which travel through the human body under the control of computers. Drugs would act at the specific site, and their side effects can be avoided by reducing the effective total dosage needed to treat the patient.[16] Targeted drug and gene delivery system have been developed by Osaka University in Japan (2003). On the same track, SWRI (South West Research Institute) developed nanocapscules, which deliver drug, antibiotics, and vaccine at the specific site with hardly any side effects.[1]

6. Nanodentistry

In the year 2000, the term and may be the field of nanodentistry were born. As nanomedicine advanced, dentistry also started evolving in the field of Nanotechnology. It is envisaged that nanotechnology will affect the fields of diagnosis, materials, restorative dentistry, and surgery. These exciting new branches namely nanorobotics, nanodiagnosis, nanomaterials, and nanosurgery and nanodrugs would profoundly impact clinical dentistry in the not-so-distant future. Science fiction will soon become reality.

7. Nanorobotics

Nanotechnology is about manipulating a matter atom-by-atom and utilizing nanorobots to assemble things from atomic and molecular building blocks. Nanorobots are theoretical microscopic devices in the range of 1–100 nm, which allow us to construct crystals, as incredibly fine-grained atomic

structures, following a detailed blueprint.[17] These are carbon-based molecules which work as machines. They derive energy from the cells and are under the command of the dentist via acoustic signals. The main element in their structure is carbon in the form of diamond/fullerene because of its high strength and inertness.[15] These are computer-controlled microscopic devices working at the level of atoms and molecules. Its components are 100 nm manipulating arms, 10 nm sorting rotors, and smooth super hard surfaces made of atomically flawless artificial diamond.[4]

Nanorobots tend to have very high positional accuracy by navigational network. After the completion of their desired actions, they are theorized to be removed from the human body by human excretory channels.

In Orthodontics, nanoparticles can be applied for rapid and painless procedures for tooth straightening, rotating, and vertical repositioning within minutes to hours. But the realization of such a theoretical idea is still a few years away. Dr. Sims proposed that the use of brackets can be replaced by nanorobots which are programmed to control bone and periodontal ligament response to achieve tooth movement.[7,18]

One area where nanotechnology would definitely benefit dentistry is dental hypersensitivity. Hypersensitive teeth are supposed to have dentinal tubules, which have twice the diameter of nonsensitive teeth and eight times more surface density of dentinal tubules.[1] Reconstructive dental nanorobots can selectively and precisely occlude the dentinal tubules.[16] Nanorobots can complete the journey to the pulp chamber in approximately 100 seconds.[10] Thus its recovery is quick and permanent.

Nanorobots may soon help in overcoming the painful and stressful procedure of local anesthesia administration. A colloidal solution containing millions of active analgesic/anesthetic nanorobots will be applied to the patient's gingiva. Through gingival sulcus, lamina propria, and dentinal tubules, it will reach the pulp within a few minutes. These nanorobots, which are controlled by dentist through acoustic signaling, are basically computer-controlled devices. A dentist will have the ability to command the nano-robots to instantly reverse the anesthesia. After the surgical procedures have been completed, then the dentist makes the nanorobots to restore all the sensations.[10]

Tschoppe et al. stated that caries can be prevented with toothpaste containing nanohydroxyapatite as well as remineralisation of enamel, and dentin can be enhanced.[7]

8. Nanodiagnostics

Nanotechnology supplements the diagnosis and treatment of oral cancer. Nanotechnology detects biomarkers of tumor cells and thus discover them earlier and increase sensitivity of test.

Metallic nanoparticles such as gold nanoparticles (AuNPs) are being investigated to overcome the limitations of imaging and chemical-based diagnostic technique. Kah et al. (2007) demonstrated the use of gold nanoparticles with Raman spectroscopy to analyze the chemical changes in the saliva in oral cancer patients. Huang et al. (2007) conjugated the gold nanorods with anti-epidermal growth factor to differentiate between malignant and nonmalignant keratinocyte cells.[5] Such a technology is super-efficient at diagnosing cell-changes. The false-negative rate of diagnosis would be virtually zero. Nanoparticles have extremely high surface area due to small size of atoms because of which various functional groups get attached to them and thus they may bind to tumor cells.[19]

Quantum dots have been used as contrast agents in vivo and in vitro for MRI (Magnetic Resonance Imaging) and ultrasound. Quantum dots are inorganic semiconductor nanocrystals of cadmium-selenide, which are $<$10 nm and are used as probes for diagnosis of oral cancer. Quantum dots travel via the blood stream and help in improving the visualization of tumor sites in conjunction with MRI.[5,14]

Nanoshells are also used as contrast agents with Medical Imaging Technologies. These are made up of silica and gold. In the spectral region from ultraviolet to infrared, they perform optical properties by conversion of electrical energy into light.[14]

9. Nanodental materials

Various nanomaterials can be used for restoration of decayed, carious, missing, and fractured teeth. Recent advances in nanomaterials have brought nanocomposites, nanoimpression, and nanoceramic into the domain of clinical dentistry.

Composite materials should have two important properties, i.e., strength and esthetics. Both these properties largely depend upon the filler particle size. From the traditional filler particles till microfilled particles, esthetic properties have improved but not so the strength properties. Trying to create a new material having both these properties, namely the mechanical strength and esthetic and polishing qualities, nanofillers have been introduced.[20] Nanocomposites have three different filler components namely: non-agglomerated discrete silica nanoparticles, barium glass, and prepolymerized fillers.[21] Filtek Ultimate Body and Filtek Ultimate Translucent (nanofilled composites) when compared to GC Gradia Direct Anterior (microfilled) and Filtek Z250 (microhybrid composite) nanofilled composites were found to have superior properties than other more traditional composite resins.[20]

Polymethyl methacrylate (PMMA), due to its exclusive advantages such as good optical properties, biocompatibility, easy processing, and reparability, has been used for almost all of the removable dental prostheses. But PMMA has some limitations such as poor strength, low fracture resistance, and microbial adhesion. To overcome these shortcoming nanostructuring materials such as TiO_2 and Fe_2O_3 are incorporated in the polymethyl methacrylate. After nanostructured incorporation, PMMA has improved modulus and strength, and it could maintain or improve ductility and esthetic properties. Also in this process, PMMA could develop possible antimicrobial properties.[12,22]

Ceramics have been used in prosthodontics in the manufacture of dental crowns and dentures considering these ceramics' high strength, suitable color, and low thermal and electrical conductivity. Still their high brittleness is a cause of concern. Use of nanozirconia ceramic has benefits of improved hardness and fracture toughness. Nano ceramics grains show

excellent corrosion resistance, high fracture toughness, and translucency.[12]

Nanocomposite artificial teeth are also a new development in this field. Nanoinorganic fillers are diffused in the matrix of composite. These are more durable as well as highly resistant to abrasion with superior color.[23]

In dental implants, one of the commonest reasons of failure is insufficient bone formation around the implant. For sufficient bone formation, surface of implants need to be altered, which include nanoscale topography and/or coatings for better and faster osseointegration of implants.[10] The development of nanostructured ceramic implants which will combine the inertness with a mechanical response to the dental implant alloy. Nanozirconia-alumina materials exhibit similar hardness values compared to alumina and are not susceptible to the hydrothermal instability.[24]

Bone is a natural nanostructured composite composed of organic compounds reinforced with inorganic one (hydroxyapatite crystals). Nanotechnology could also be used to treat bone defects with nano-bone graft materials. Nano-bone graft materials should fulfill the following requirements: osteoconductivity, fully synthetic, nonsintered, highly porous, and nanostructured, and which could absorb natural protein that can be degraded by osteoclasts.[24]

An ideal impression material should record the details of a patient's mouth with precision. Nanofillers are added to the polyvinylsiloxanes to improve their properties. These material exhibit better flow, improved hydrophilic properties, enhanced, detailed precision, and less voids at the margins.[10,12]

10. Nanosurgery

Nanoneedles and nanotweezers are also being developed that will make cell surgery a possibility in the near future.[24] Suture needles incorporating nanosized stainless steel crystals are being developed, which may be used to produce incisions at the cell-level.[1,24]

11. Nanodrugs

Triclosan-loaded nanoparticles are produced for the treatment of periodontal disease. Hollow spheres, core–shell structure, nanotubules, and nanocomposite can be used as periodontal drug-delivery system in near future. For the treatment of periodontal pocket, Aresin can be used, in which tetracycline is incorporated.[25]

According to Dr. Friedman, nanomaterials accelerate the process of wound healing. In mice, burn wounds were treated with curcumin nanoparticles and accelerated wound healing was observed.[26]

12. Other applications of nanodentistry

Nanosolutions are also another advancement of nanotechnology. These are unique and dispersible nanoparticles used in bonding agents. These are already available in the market from reputed companies such as 3M.[27]

Nanotechnology conceptually has reached to the level, where one day it would be possible to repair the whole tooth. Chen et al. have synthesized nanorods, which have a structure similar to enamel prisms. These hydroxyapatite nanorods possess a feature to mimic the tooth structure. These biomimetic restorations thus restore the missing tooth structure.[7]

13. Safety issues of nanotechnology

Nanotechnology has its role in every field and it can make our life easy and faster. But it has few limitations relating to our safety concerns. Nanomaterials have large surface area volume ratio due to which atoms present at the surface also increase. Thus, nanomaterials are more reactive and have increased rate of absorption through skin, lungs, and digestive tract. Thus after a prolonged use, these will get accumulated in different organs and will be transported to the other organs via blood. In the lungs, they may cause inflammation of the alveoli and subsequent cell damage. These small particles can also react with DNA, RNA, and other intracellular components and can cause mutations.[7] Nanotechnology is a relatively newer field, which works in an as yet uncharted territory. As are the benefits not yet completely realized, so are the possible threats and safety concerns. Only prolonged clinical use will determine the true potentials and threats of Nanotechnology in Medicine and Dentistry.

14. Problems faced by nanodentistry

Although we have many ideas for nanodentistry, but in reality most of them are not possible due to various challenges such as engineering challenges, biological challenges, social challenges, and many others. It is really challenging to position and assemble the molecular scale part precisely. It is difficult to manipulate the activities of different nanorobots simultaneously. Nanomaterials can be pyrogenic as well, so manufacturing biofriendly nanomaterials is also an obstacle. Social challenges such as ethics, public acceptance, and human regulation are also major concern.[4]

15. Conclusion

Nanodentistry is a multidisciplinary field of scientific research that highlights the application of new nanomaterials and devices in all the areas of human activity. Nanomaterials and nanorobots are of great interest when considering advances in nanotechnology. Although all the research activities for this promising field are at the initial stage, the results of the clinical studies have a strong potential to revolutionize the diagnosis and treatment planning as well as tissue regenerative materials for improving esthetics in dental field. However more investigations and clinical trials are required for the application of nanotechnology in oral health and dental care.

Conflicts of interest

The authors have none to declare.

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