REVIEW ARTICLE

Nanotechnology: The Emerging Science in Dentistry

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ABSTRACT

Predicting the future of any major technology is difficult. Nanotechnology or nanoscience refers to the research and development of an applied science at the atomic or molecular level (i.e. molecular engineering, manufacturing). Although the nanoscale is small in size, its potential is vast. Almost every area of human activity will be affected by future nanotechnologies. Nanotechnology is also applied to various medical fields like pharmacological research, clinical diagnosis, supplementing immune system, cryogenic storage of biological tissues. The growing interest in the dental applications of nanotechnology is leading to the emergence of a new field called nanodentistry.

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INTRODUCTION

Greatness does not come from size, surprises come in small packages. 'Nano' is derived from the Greek word which stands for 'dwarf'. Nanotechnology is the science of manipulating matter, measured in the billionths of meters or manometer, roughly the size of two or three atoms.[1] Nanotechnology is very diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale to investigating whether we can directly control matter on the atomic scale.[2]

Origins

The topic of nanotechnology was touched upon by 'there's plenty of room at the bottom', a talk given by physicist Richard Feynman at an American Physical Society meeting at Caltech on December 29, 1959. At the meeting, Feynman announced two challenges, and he offered a prize of $1000 for the first individuals to solve each one. The first challenge involved the construction of a nanomotor, which, to Feynman's surprise, was achieved by November 1960 by William McLellan. The second challenge involved the possibility of scaling down letters small enough, so as to be able to fit the entire Encyclopedia Britannica on the head of a pin; this prize was claimed in 1985 by Tom Newman.[3] The term 'nanotechnology' was first defined by Norio Taniguchi of the Tokyo Science University in a 1974 paper as follows: 'Nanotechnology' mainly consists of the processing of, separation, consolidation and deformation of materials by one atom or one molecule. Nanotechnology is on the verge of initiating extraordinary advances in biological and biomedical sciences that would be associated with both providing the tools for improved understanding of fundamental building blocks of materials and tissues at the nanoscale and designing technologies for probing, analyzing and reconstructing them.[4]

Fundamental Concepts

One nanometer (nm) is one billionth, or 10^{-9}, of a meter. By comparison, typical carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range 0.12 to 0.15 nm, and a DNA double-helix has a diameter around 2 nm. To put that scale in another context, the comparative size of a nanometer to a meter is the same as that of a marble to the size of the earth. Or another way of putting it: A nanometer is the amount an average man's beard grows in the time it takes him to raise the razor to his face.[5] Two main approaches are used in nanotechnology. In the 'bottom-up' approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the 'top-down' approach, nano objects are constructed from larger entities without atomic-level control.[6]

The various nanoparticles are as follows:[7]

1. Nanopores
2. Nanotubes
3. Quantum dots
4. Nanoshells
5. Dendrimers
6. Liposomes
7. Nanorods
8. Fullerenes
9. Nanospheres
10. Nanowires
11. Nanobelts
12. Nanorings
13. Nanocapsules

Applications of Nanotechnology in Dentistry

Material Science

Nanotechnologies started with the beginning of the era of microfills. Nowadays, the most commonly used resin composites are microhybrids and nanofilled composites, comprising filler particles ranging from approximately 20 to 600 nm. Xu et al reported resin-based composites containing calcium fluoride nanoparticles in a whisker-reinforced resin matrix with sustained fluoride release had values exceeding those of conventional and resin-modified glass ionomers.[8] In a different direction, case in phosphopeptide amorphous calcium phosphate (CPP-ACP) are nanoparticles that bind to biofilms, plaque, bacteria, hydroxyapatite and the surrounding soft tissue, localizing bioavailable calcium and phosphate and serving as mineral precursors for remineralization.[9] In the case of biomaterials, nanoparticulate materials appear to strongly influence the host response at both cellular and tissue levels, which makes nanotechnology particularly attractive for dental implants. Fabrication of nanostructures has been intensively explored in an attempt to develop the right combinations of chemistry, microstructure and topography to increase the surface osseoconductivity and at the same time improve the durability and resistance to failure, which are the main limitations of the dental implants and coatings.[10] Two recent *in vitro* studies have provided interesting insights based on the theme of nanofibers and nanocrystals. Nanofibrillar silicate crystals can be used either alone or in conjunction with nanofibers, to reinforce BIS-GMA/TEGDMA-based nanocomposites.[11,12] In a similar direction, several other recent studies by Xu et al have evaluated the incorporation of nanosized $CaPO_4$ particles into resin-based composites, with a resulting improvement in stress-bearing capacity as well as ion release that could inhibit caries.[13]

Genetically engineered peptides for inorganics (GEPIs) have recently been hypothesized by Zhou and colleagues to have practical implications for tooth repair, if they can be engineered to recognize inorganic HA and form a hybrid with it.[14]

Role of Nanotechnology in Dental Biofilm

Nanotechnology has been used to study the dynamics of demineralization/remineralization process in dental caries by using tools, such as atomic force microscopy (AFM) which detect bacteria induced demineralization at an ultrasensitive level. Using AFM the correlation between genetically modified *Streptococcus mutans* and nanoscale morphology has been assessed.[15] The nanoscale cellular ultrastructure is a direct representation of genetic modifications as most initiate changes in surface protein and enzyme expression, where host- cell nutrient pathways and immune response protection likely occur. The surface proteins and enzymes, common to *S. mutans* strains are a key contributor to the cariogenicity of these microbes. Chalmers et al had applied quantum dots (QD) (semi-conductor nanocrystals) based primary immunofluorescence for *in vitro* and *in vivo* labeling of bacterial cells and compared this approach with the fluorophore-based primary immunofluorescence.[16]

A new silver nanotechnology chemistry has proven to be effective against biofilms silver works in a number of ways to disrupt critical functions in a microorganism. For example, it has a high affinity for negatively charged side groups on biological molecules, such as sulfydryl, carboxyl, phosphate and other charged groups distributed throughout microbial cells. Silver attacks multiple sites within the cell to inactivate critical physiological functions, such as cell wall synthesis, membrane transport, nucleic acid (RNA and DNA) synthesis and translation, protein folding and function and electron transport.[17]

Local Anesthesia

In the era of nanodentistry, a colloidal suspension containing millions of active analgesic micron-size dental robots will be instilled on the patient's gingiva. After contacting the surface of crown or mucosa, the ambulating nanorobots reach the pulp via the gingival sulcus, lamina propria and dentinal tubules, guided by chemical gradient, temperature differentials, all under the control of dentist with the help of onboard nanocomputer.[18]

Nanotechnology and Its role in the Management of Periodontal Diseases

Using natural processes as a guide, substantial advances have been made at the interface of nanomaterials and biology, including the fabrication of nanofiber materials for three-dimensional cell culture and tissue engineering.[19] Nanoparticles are being developed for a host of biomedical and biotechnological applications including drug delivery, enzyme immobilization and DNA transfection.[20] Recently, Pinon-Segundo et al produced and characterized triclosan-loaded nanoparticles by the emulsification–diffusion process, in an attempt to obtain a novel delivery system adequate for the treatment of periodontal disease.[21] Drugs can be incorporated into nanospheres composed of a biodegradable polymer, and this allows for timed release of the drug as the nanospheres degrade. This also allows for site-specific drug delivery. A good example of how this technology might be developed is the recent development of arestin in which tetracycline is incorporated into microspheres for drug delivery by local means to a periodontal pocket.[22]

Dental Hypersensitivity

Natural hypersensitive teeth have eight times higher surface density of dentinal tubules and diameter with twice as large as nonsensitive teeth. Reconstructive dental nanorobots, using native biological materials, could selectively and precisely occlude specific tubules within minutes, offering patients a quick and permanent cure. On reaching the dentin, the nanorobots enter dentinal tubular holes that are 1 to 4 µm in diameter and proceed toward the pulp, guided by a combination of chemical gradients, temperature differentials and even position of navigation, all under the control of the nanocomputer as directed by the dentist.[23]

Orthodontic Treatment

Sliding a tooth along an archwire involves a frictional type of force that resists this movement. Use of excessive orthodontic force might cause loss of anchorage and root resorption. In a study published by Katz, a reduction in friction has been reported by coating the orthodontic wire with inorganic fullerene-like tungsten disulfide nanoparticles (IF-WS_2), which are known for their excellent dry lubrication properties. In future, orthodontic nanorobots could directly manipulate the periodontal tissues, allowing rapid and painless tooth straightening, rotating and vertical repositioning within minutes to hours.[24]

Toxicity of Carbon Nanoparticles in Humans

The extensive application of nanomaterials in a wide range of products for human use possesses a potential risk for toxicity risk to human health and environment. American health association concluded that short-term exposure to elevated particulate matter concentrations in outdoor air significantly contributes to incresed to acute cardiovascular mortality, particularly in at risk subset of population. Nanomaterials may have efects on health due to their size, shape, charge or other factors, which are not directly predictable from mass concentration measurements.

Donalsn et al and Oberdorstan concluded in their review that ultrafine particles of low intensity and low solubility material are more inflamogenic in the rat lung than large particles of the same material. Nanoparticles are able to penetrate deeply into the respiratory tract and once deposited may translocate to blood and to other sites distant from their portal of entry, such as liver, spleen, kidney and brain.[25]

CONCLUSION

Nanotechnology will change dentistry, healthcare and human life more profoundly than many developments of the past. As with all technologies, nanotechnology carries a significant potential for misuse and abuse on a scale and scope never seen before. Molecular technology is destined to become the core technology underlying all of 21st century medicine and dentistry.

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