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Nanotechnology and its role in dentistry: A review.

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Abstract

It is difficult to predict the future of any major technology. Nanotechnology is a science that deals with the research and development of materials and devices at the atomic or molecular level. Almost every aspect of human life will be influenced by future nanotechnologies. With the advancement in the technology, it is also getting incorporated in various medical fields including dentistry (nanodentistry). Though it is relatively new in dentistry, there is ever growing interest in application of nanodentistry both in the development of materials and devices.

Introduction

'Nano' is derived from the Greek word nan(n)os which means 'dwarf'. Nanotechnology is a science that deals with manipulation of matter at the atomic level [1]. It is a vast field that ranges from broadening of standard device physics to novel approaches based upon molecular self-construction, and/or from developing new materials having dimensions at the nanosclae level to exploring the ideas whether matter can be directly controlled on the atomic scale [2].

Richard Feynman, a physicist, was the first person who shed a light on the topic of nanotechnology during the historical talk 'there's plenty of room at the bottom', at an American Physical Society meeting at Caltech on December 29, 1959. During his lecture, he put across two challenges and $1000 prize money to be given to the individual who was able to solve them. Feynman got a surprise when his first that required building a nanomotor was achieved by Willlaim McLellan (November 1960) in less than a year's time. However, it took some time before Tom Newman in 1985 was able to resolve the second challenge that demanded scaling down of the letters small enough that an entire Encyclopedia Britannica could fit on the head of a pin [3].

The term 'nanotechnology' was first presented by Norio Taniguchi (1974)[4], who defined it as a "mainly consisting of the processing, separation, consolidation and deformation of materials by one atom or one molecule". He further stated that nanotechnology is on the edge of opening new horizons in both biological and biomedical sciences that would not only be linked with offering newer tools for better interpretation of fundamental building blocks of materials and tissues at the nanosclae level, but also designing tools for investigating, analyzing and rebuilding them.

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Basic concepts

One nanometer (nm) is one billionth, or 10^{9}, of a meter. To put this in perspective, the length of a typical carbon-carbon bond or the space between these atoms in a molecule, ranges from 0.12 to 0.15 nm, and the diameter of a DNA double-helix is around 2 nm. To put this in a simpler way, the relative size of a nanometer to a meter is the same as that of a marble to the size of earth.

In nanotechnology, two main approaches are used. Firstly, the 'bottom-up' approach, where construction of materials and devices is done from molecular components that self-assemble chemically based on the principles of molecular differentiation. Secondly, 'top down' approach, where construction of materials and devices is done from large units without any control at the atomic level [5]. There are a number of nanoparticles used including nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes, nanospheres, nanowires, nanobelts, nanorings and nanocapsules [6].

Application of nanotechnology in Dentistry

Material science

Nanotechnology in dental material sciences started with the introduction of microfills. Today, the most commonly used resin composites are microhybrids and nanofilled composites, comprising of filler particles ranging from 20 – 600 nm. Studies have reported better values in regards to sustained fluoride release among resin composites that contain calcium fluoride nanoparticles in a whisker-reinforced resin matrix than other materials such as conventional and/or resin-modified glass ionomers[7]. In addition, there are nanoparticles such as casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) that have the ability to serve as mineral precursors for remineralization by attaching themselves to biofilms, plaque, bacteria, hydroxyapatite and the surrounding soft tissues and as a result localizing bioavailability of calcium and phosphate [8].

In regards to biomaterials, nanotechnology has gained an increasing interest by researchers, particularly in case of dental implants. This is mainly due to the impact of nanoparticles on host responses at both cellular and tissue levels. Extensive work has been done in an attempt to fabricate nanostructures that have appropriate chemical and structural combinations in order to achieve an increased surface osseoconductivity as well as improved

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Review

durability and resistance to failure[9]. This will help overcome the main limitations of dental implants and coating.

Two recent in vitro studies have presented some interesting observations on the subject of nanofibers and nanocrystals. The authors reported that BIS-GMA/TEGDMA-based nano-composites can be markedly reinforced by incorporation of nanofibrillar silicate crystals either alone or in combination with nanofibers [10, 11]. In a similar way, other studies have reported marked improvement in stress-bearing and ion releasing capacities of resin-based composites by incorporation of nanosized CaPO4 particles [12]. These findings are very encouraging and may play a significant role in inhibition of dental caries.

Zhou and colleagues reported a novel biomaterial for tooth repair. They hypothesized that genetically engineered peptides for inorganics (GEPIs) may have practical implications for tooth repair, if they can be engineered to recognize inorganic HA crystal and form a hybrid with it [13].

Dental biofilm

Nanotechnology has been widely utilized to investigate the dynamics of the demineralization/remineralization process in dental caries by using tools, such as atomic force microscopy (AFM) which has the ability to detect bacteria induced demineralization at an ultrasensitive level. Studies have assessed the association between Streptococcus mutans (S. mutans) and nanoscale cellular ultrastructure using AFM [14]. Since most changes originate in surface protein and enzyme expression, the evaluation of nanoscale morphology is important and offers a direct representation of genetic modifications as it is where host-cell nutrient pathways and immune protection response take place. The surface protein and enzymes, common to S. mutans strains are among the key contributors to the caries inducing ability of these microbes. Some studies have employed certain semi-conductor nanocrystals such as Quantum dots (QD) for in vitro and in vivo labeling of bacterial cells and compared this approach with the conventional fluorophore-based primary immune-fluorescence [15].

A new silver-based nanotechnology has been recognized and appeared to be effective against biofilms by disrupting critical functions in a microorganism [16]. It has shown to have high affinity for negatively charged side groups such as carboxyl, sulfydryl, phosphate as well as other charged groups distributed throughout microbial cells. It works on the principle that multiple sites within the cell are attacked by the silver causing deactivation of critical physiological functions. The functions that are affected include cell wall synthesis, membrane transport, nucleic acid (RNA and DNA) synthesis and translation, protein folding and function and electron transport.

Local anesthesia

In nanodentistry, local anesthesia will be administered by instilling a colloidal suspension containing millions of active analgesic micron-sized dental robots on the patient's gingiva. After the suspension comes in contact with the surface of the tooth or mucosa, the embedded nanorobots start moving towards the pulp via the dentinal tubules, lamina propria and/or gingival sulcus. This movement is directed by chemical gradient and temperature differences and is always under the control of dental professionals with the help of onboard nanocomputer [17]. In comparison to conventional local anesthesia methods, nanorobotic analgesics offer far greater benefits including better patient comfort and reduced anxiety since no needle is used. In addition, nanorobotic analgesics provide better selectivity and control over the effect of the analgesia, fast and completely reversible action and avoidance of most of side effects and complications.

Periodontal diseases

A number of significant developments have been made at the juncture of nanomaterials and oral biology. This includes manufacturing of nanofibers that provide materials for three dimensional cell structure as well as tissue engineering [18]. Nanoparticles are being developed for a host of biomedical and biotechnological applications including drug delivery, enzyme immobilization and DNA transfection [19]. Recently, triclosan-loaded nanoparticles are manufactured and characterized using the emulsification-diffusion method[20]. This was mainly done in order to develop a new delivery system that is appropriate for the treatment of periodontal diseases. Drugs that need to be administered are stored into nanospheres that are composed of a biodegradable polymer, thereby allowing the programmed release of the drug as the nanospheres degrade. This also gives an option for site-specific delivery of the drug. Development of arestin in recent years is one good example of how this technology may be utilized. In case of arestin, the drug tetracycline is administered locally to a periodontal pocket by incorporating it into microspheres [21].

Dental hypersensitivity

Nanotechnology may play a significant role in dental hypersensitivity. Dentinal tubules possess eight times higher surface density and two times larger diameter among hypersensitive teeth compared to non-sensitive teeth. Dental nanorobots that are manufactured using indigenous biological materials could selectively and accurately obstruct dentinal tubules within minutes, thereby offering a fast and lasting remedy. The nanorobots on reaching the dentin start moving towards the pulp via dentinal tubules that are 1 – 4 µm in diameter. This whole process is guided by chemical gradient and temperature differences and is always under the control of the dental professional with the help of onboard nanocomputer [22].

Orthodontic treatment

A frictional type of force is required to slide a tooth along an archwire. However, use of excessive orthodontic force in this regards may cause loss of anchorage and in some

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cases even root resorption. Nanotechnology may be helpful to overcome these issues. Use of inorganic fullerene-like tungsten disulfide nanoparticles (IF-WS2) as a coating on the surface of orthodontic wire have shown to reduce the friction force because of exceptional dry lubrication characteristics of IF-WS2[23]. Hopefully in the future, orthodontic nanorobots could directly influence the periodontal tissues, allowing fast and effortless tooth straightening, rotating and vertical repositioning within minutes to hours.

Oral cancer

In oral cancer diagnostics, limitations in the imaging and chemical-based techniques have been investigated and an attempt is made to overcome them with the use of metallic nanoparticles. Studies have reported that the incorporation of gold nanoparticles in surface enhanced Raman scattering (SERS) resulted in enhanced Raman spectroscopy signals for the analysis of cancer-related chemical changes in saliva[24]. SERS spectra of saliva obtained show marked differentiation between normal and oral cancer patients. This clearly demonstrate SERS-based saliva assay as a potential tool for early diagnosis of oral cancer. Some studies have reported other physiochemical properties of gold nanoparticles and demonstrated their use as optical probe in the early detection of oral cancer [25]. When used as an optical probe, gold nanoparticles can provide an optical contrast to discriminate between normal and malignant cells.

Potential health hazards

In recent years, there has been an increase in the application of nanotechnology in a wide range of products that involve human use. In addition to all the benefits this technology has to offer, there is a potential risk of toxicity to human health as well as the environment. Studies have shown a significant association of increased cardiovascular mortality among the population that are exposed to the elevated particulate matter in outdoor environment [26]. The health hazards of nanoparticles depends on their size, shape and charge and may not be directly predictable from mass concentration measurements. Overall, the potential harms caused by nanomaterials and the dosage at which they are caused, has not been explained yet and therefore further investigations are needed.

Conclusion

Nanotechnology in dentistry is still new and faces many significant challenges in realizing its tremendous potential. There is no doubt in saying that it will profoundly change healthcare in particular and human life in general. However, there are some serious concerns such as public approval, ethics, regulation and human safety that need to be addressed before embarking this technology. Time, specific developments, financial and scientific resources and human needs will determine which of the applications to be achieved first.

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Review

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