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REVIEW ARTICLE

NANOTECHNOLOGY: TINY PARTICLES WITH HUGE IMPACT

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ABSTRACT

Nanotechnology is the science of manipulating matter, measured in the billionths of meters, roughly the size of two or three atoms. Nanotechnology has revolutionized all fields including health care and engineering, and dentistry being no exception. The way forward for nanotechnology in the various fields of dentistry seems to be full of possibilities as dental practices have the potential to be performed using these nano-eqiupments and devices. The recent nanotechnology innovations are increasingly providing a suitable solution for the treatment of many dental illness including periodontal disease. Therefore, a better understanding of the science behind nanotechnology is inevitable to appreciate how nanodentistry will make possible the maintenance of near perfect oral health. The present paper focuses on the impact created by nanotechnology in the field of Periodontology at preventive, diagnostic and therapeutic level, and also the current status of nanotechnology-based approaches for periodontal disease therapy.

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INTRODUCTION

Nanotechnology is the science of manipulating matter, measured in the billionths of meters, roughly the size of two or three atoms. Nanotechnology is an extremely diverse and multidisciplinary field, ranging from novel extensions of conventional physics to completely new approaches based upon molecular self-assembly, to developing new materials and machines with nanoscale dimensions (Verma, 2014). The nanotechnology is progressing swiftly that it will not be wrong to call it as *Magic Bullet* as said by the Nobelist Paul Erlich. As Nanotechnology has revolutionized all fields including health care and engineering, and dentistry being no exception. A dental field of nanotechnology called nanodentistry is very promising and have demonstrated various treatment opportunities in dentistry.

History: The word nano originates from the Greek word "dwarf". The concept of nanotechnology was first detailed in 1959 by Richard Feynman in a lecture titled, "There's plenty of room at the bottom (Feynman, 1966)". The term ''nanotechnology'' was coined by Nario Taniguchi in 1975, though it was not widely known. Feynman's idea remained largely undiscussed until the mid-1980s. It was K. Eric Drexler (Drexler, 1986) who popularized the potential of molecular nanotechnology through his book "Engines of Creation" published in 1986 and also recoined the term "Nanotechnology". Robert Freitas in the year 2000 coined the term "nanodentistry (Freitas, 2000)". He developed visions using nanorobots for orthodontics, nanomaterials, and robots in dentifrices-dentifrobots. Although most of his ideas were and remain science fiction, these ideas are gradually being realized into practice.

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Approaches to nanodentistry

Bottom-up approaches: Building up particles by combining atomic elements. Here, nanoparticles are produced directly.

Top-down approaches: Using equipment to create mechanical nanoscale objects .Creation of small structures by using larger entities in guiding their assembly.

Nanorobots: Nanorobots are theoretical microscopic devices measured on the scale of nanometers (Figure 1). They would respond to definite programs enabling clinicians to execute accurate procedures at the cellular and molecular level (Bhardwaj, 2009).

Mechanism of action of nanorobots: The powering of the nanorobots can be done by metabolizing local glucose sugars and oxygen, the nanorobot will have other biochemical or molecular parts depending on its task (Saxena, 2015). Nanorobot will have a nanocomputer on board which will stock and execute planned missions, will receive and process signals and external stimuli, will communicate with other nanocomputers and will respond to external control and monitoring devices and will possess the contextual knowledge in order to ensure the correct functioning of the nanomechanical devices (Freitas, 2000).

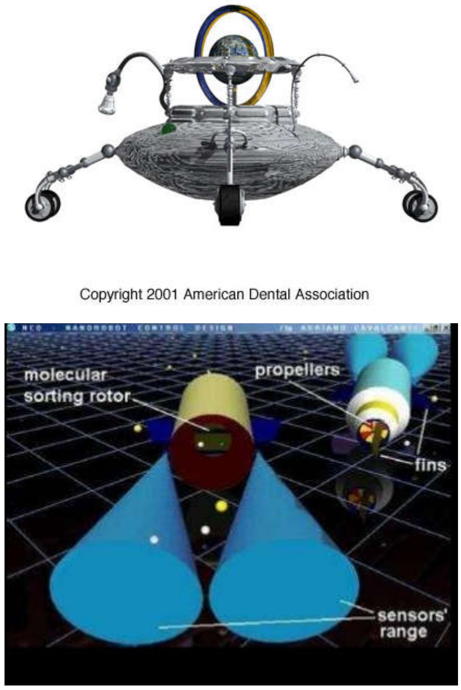

Figure 1. Dental Nanorobot

Applications of Nanotechnology in Periodontology: The recent nanotechnology innovations are increasingly providing a suitable solution for the treatment of many dental illness including periodontal disease. Nanotechnology has already created an impact in the field of preventive, diagnostic and therapeutic level.

Preventive nanodentistry

Nanorobotic dentifrice [Dentifrobots]: Sub-occlusally dwelling nanorobots delivered by dentifrice (Figure 2) patrol all supra-gingival and subgingival surfaces with their continuous and fast movement (1–10 µm/ s) metabolizing trapped organic matter into harmless and odourless vapors and prevents the calculus accumulation and are safely self-deactivated when they are swallowed. Being suspended in liquid and able to swim about, devices would be able to reach surfaces beyond reach of toothbrush bristles or the fibers of floss. They also prevent tooth decay and provide a continuous barrier to halitosis (Bhardwaj,. 2009; Saravana, 2006).

Figure 2. Dentifrobots

Nano-toothbrush: Researchers developed a nano-toothbrush, by incorporating nanogold or nanosilver colloidal particles between toothbrush bristles. In addition to its ability to improve upon mechanical plaque removal, researchers reported an antibacterial effect of the added gold or silver which could ultimately lead to a significant reduction in periodontal disease (AlKahtani, 2018).

Diagnostic nanodentistry: Nanotechnology offers significant promise in the disease's early diagnosis even at molecular and cellular level.

Atomic force microscopy and oral biofilms: It offers a breakthrough in characterization of bacteria as well as measurement of their adhesion to different substrates. It also provides precise information on biomechanical interactions of antibacterial drugs with a bacterial cell. With nanomechanical biosensors, AFM cantilever, a real-time scanning of a live bacterial cell with high sensitivity was made possible (Neel, 2015).

Biochips and salivary biomarkers: Salivary diagnostics is a dynamic and emerging field utilizing nanotechnology and molecular diagnostics to aid in the diagnosis of oral and systemic disease. Possibly one of the most exciting uses of nanotechnology in oral health diagnostics comes from the emergence and development of biochips. Lab-on-a-chip (LOC) is a device which integrates several laboratory functions on a single chip. Assays are performed on chemically sensitized beads populated into etched silicon wafers with embedded fluid handling and optical detection capabilities. This device has been used to assess the levels of interleukin-1 beta, C-reactive protein, and matrix metallo proteinase-8 and other molecules in whole saliva, which are potential use of these biomarkers for diagnosing and categorizing the severity and extent of periodontitis (Herr, 2007). *Christodoulides et al* have developed an electronic microchip-assay to detect C-reactive protein, which is a biomarker for inflammation associated with periodontal disease at the picogram per milliliter level (Christodoulides, 2005).

Therapeutic nanodentistry: Nanotechnology represent a promising tool for therapeutic approach in almost all specialities in dentistry.

Dentin Hypersensitivity Cure: Dentin hypersensitivity is a pathological phenomenon caused by changes in pressure transmitted hydrodynamically to the pulp. Dentinal tubules of hypersensitive tooth exhibits eight times higher surface density and twice the diameter. Dental robots could selectively and precisely occlude these tubules using native biological materials offering patients a rapid and permanent cure (Freitas, 2000).

Inducing anesthesia: A colloidal suspension containing millions of active analgesic micron-size dental robots will be instilled on the patient's gingiva. Migration of nanorobots from tooth surface to the pulp occurs in l00 seconds and they establish control over nerve impulse. When the dentist presses the hand held control, the selected tooth is immediately anaesthetized. After the procedure is completed, the dentist orders the nanorobots to restore all sensation and egress from the tooth. Nanorobot analgesia offers greater patient comfort, reduces anxiety, no needles, greater selectivity, controllability of analgesic effect; fast and completely reversible action; avoidance of side effects and complications (Verma, 2014; Freitas, 2000).

Nanomaterials for Periodontal Drug Delivery: Nanotechnological drug delivery approaches provides an avenue by which therapeutic molecules could been capsulated/loaded in carriers, such as nanoparticles or scaffolds, to allow targeted, sustained and controlled release to the intended location (Neel, 2015).

Nanoencapsulation: Nanomaterials, including hollow spheres, core-shell structure, nanotubes and nanocomposite, have been widely explored for controlled drug release. Drugs can be incorporated into nanospheres composed of a biodegradable polymer thus allowing for timed release of the drug as the nanospheres degrade. Pinon– Segundo *et al*. (2005) studied Triclosan-loaded nanoparticles, 500 nm in size, used in an attempt to obtain a novel drug delivery system adequate for the treatment of periodontal disease. These particles were found to significantly reduce inflammation at the experimental sites. Poly (lactic-co-glycolic acid) PLGA nanoparticles were developed to encapsulate minocycline for periodontal infections. The nanoparticles of size 85–424 nm have an entrapping efficiency of up to 29.9%. The release was shown to be sustained for several weeks, which resulted in a considerable antibacterial effect compared to the minocycline-free nanoparticles (Neel et al., 2015; Aminu, 2017).

Nanofibers: Nanofibers have often been shown to be excellent matrices for the sustained delivery of drugs mainly due to their high surface area. For PDL regeneration, nanofibers composed of Poly-ε-caprolactone (PCL) L effectively encapsulated metronidazole benzoate showed prolonged sustained drug release for at least 19 days and can be used as a retentive, locally controlled delivery system for metronidazole in periodontal diseases treatment. Similarly, low-dose controlled-release PCL nanofibers containing doxycycline showed sustained drug release and can be used as a retentive controlled delivery system for the treatment of periodontal diseases (Neel, 2015; Aminu, 2017).

Laser plasma application for periodontics: When nanoscale (20-50 nm) titanium dioxide (TiO_2) particle sizes are presented on the human skin in the form of a gel-like emulsion, these exhibit some interesting properties such that when irradiated with laser pulses, these particles can be optically broken down with accompanying effects such as shock wave, micro-abrasion of hard tissue, and stimulation of collagen production. Its clinical applications include periodontal treatment, depigmentation and incision of soft tissue without anesthesia (Gopinadh, 2015).

Nanomaterials to induce bone growth: As the particle size decreases, the surface area becomes larger in volume. Nanobone uses this basic principle of nanostructure. Various alloplastic bone grafts with nanoscale particle sizes are being developed. One of the recent and most promising among them are nano-hydroxyapatite (n-HAP) bone grafts, which are available in crystalline, chitosan-associated and titanium-reinforced forms[15]. These n-HAP composite bone graft scaffolds are highly biocompatible, have superior mechanical properties, and induce better cellular responses compared to 'plain' chitosan scaffolds (Chesnutt, 2009).

Nanotechnology in dental implants: Nanotechnology can be used in the surface modifications of dental implants. The coating of nanoparticles over the dental implants, improves the adhesion and integration of surrounding tissues. An interesting feature of nanoscale topographic surfaces is the selectivity of cell adhesion. Studies have demonstrated the relative diminution of fibroblast adhesion compared to osteoblast adhesion when nano- and micron-structured surfaces were evaluated .[17] For example, on nano-sized materials, the affinity ratio between osteoblasts and fibroblasts was 3 to 1. In the conventional materials the ratio was 1 to 1 (Webster, 2000). In addition to this, bacterial adhesion and proliferation is also diminished on nanophase materials. Decreased bacterial colonization on nanostructured TiO2 and ZnO is observed even though these surfaces promote osteoblast adhesion and differentiation (Colon, 2006).

Various nano-structured implant coatings have been developed:

- Nanostructured diamond which possess improved hardness, toughness, low friction.
- Nanostructured hydroxyapatite coatings which possess increased osteoblast adhesion proliferation and mineralization.
- Nanostructured metalloceramic coatings which possess ability to overcome adhesion problems.

Challenges: Though nanotechnology offers several promises in the field of dentistry, it still faces many significant challenges in realizing its tremendous potential (Verma, 2014).

- Engineering challenges such as feasibility of mass production technique and precise positioning and assembly of molecular scale part.
- Biological challenges such as developing biofriendly nanomaterial and ensuring compatibility with all intricate of human body.
- Social challenges such as ethics, public acceptance, cost factor, regulation and human safety.

Risks: Some of the risks associated with the development of nanotechnology (Satyanarayana, 2011):

- **Crosses blood brain barrier:** Nanoparticles are so small that they could easily cross the blood brain barrier, a membrane that protects the brain.
- **Gray goo**: Scenario where synthetic nanosize devices replace all organic matters.
- **Green goo**: Scenario where nanodevices made of organic material wipe out the earth.
- **Black goo**: Scenario in which destructive nanomachines are developed and used for warfare or terrorist purpose.
- **Trans humans**: Nanotechnology makes it possible for us to enhance ourselves physically and mentally making us smarter, stronger. The threat is could we continue calling ourself as humans or trans humans, creating two races wealthy trans humans and poorer unaltered people.

Future: Nanotechnology is anticipated to change health care in a fundamental way. The science and applications of nanotechnology are constantly evolving as we witness new products being launched into the market. Research to improve upon existing nanomaterials is still in progress, with future directions towards more logical and cost effective nano-biosensing diagnostic aids, in addition to novel oral drug delivery systems to disrupt biofilm formation and reduce the incidence of caries and periodontal disease.

Conclusion

Nanotechnology will bring tremendous changes into the fields of medicine and dentistry. No field will remain untouched by nanotechnology. As newer sciences and associated technologies make their way into interdisciplinary dentistry while creating a huge impact on it, what remains to be seen is how well can the whole fraternity take advantage of the encouraging situation and scale new heights in the field that were deemed impossible previously. Development of nanodentistry will make possible the maintenance of near perfect oral health.

In short, The Next Big Thing Is Really Small!!!

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