Nanodentistry: Today and Tomorrow

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ABSTRACT

Nanodentistry is an innovation, a branch that makes possible the maintenance and upgradation of oral health care yet more precise and by employing nanomaterials, biotechnology, including tissue engineering & ultimately dental nanorobotics. Nanotechnology has a special consideration in orthodontics due to its capability to comprehend the orthodontic treatment as well as treating the aftermath of contemporary treatment modalities. An example of which is the advent of nanorobots for tooth repositioning and rotation corrections as they have the capability of manipulation of periodontal tissue including gingival fibres, periodontal fibres and alveolar bone. As their role in treating the aftermath of orthodontic treatment, nanorobots aid in tooth remineralization and bone augmenting owing to its mechanism of action. This review article highlights the history of nanotechnology, the mechanism of action, components, and its importance in orthodontics and aesthetics dentistry.

Keywords: *Nanodentistry, Nanorobots, Nubots, Biochips, Nanomedicine*

INTRODUCTION

To grow, the only constant is to keep changing[1]. If we wish to achieve something new in life, change is required and science is not an exception to it. For better care of patients in clinical sciences like dentistry and medicine the research is the backbone of newer technologies[2]. The prime objective of oral health care is restoration of oral structures in the optimum state of functional equilibrium and its rehabilitation[3]. This gives way to the continuous research for the upgradation of technologies as well as treatment modalities. The broad field of nanomedicine seeks to address many of the needs in biology, creating the not so quite as broad discipline of nanobiotechnology. Dental science is promply heading towards precision, efficacy and minimum invasive diagnostic and treatment aids and one of the promising answer to it is nanotechnology. Nanodentistry will make possible the maintenance of comprehensive oral health by employing nanomaterials, including tissue engineering, and ultimately, dental nanorobots.[4]

HISTORY

"Nano" is derived from the greek word for 'dwarf'.[5] The field of nanotechnology was first predicted by Richard P Feynman who was a nobel laureate in Physics, in 1959 with his famous lecture entitled, "There's plenty of Room at the Bottom".[6] The late Nobel Prize winning physicist Richard P. Feynman speculated the potential of nanosize devices as early as 1959. In his historic lecture, he concluded saying, 'this is a development which I think cannot be avoided."

Feynman's idea remained largely undiscussed until the mid-1980s, when K. Eric Drexler[7] published "Engines of Creation", a book to popularize the potential of molecular nanotechnology in 1986 and introduced the term nanotechnology[7].

The term "nanotechnology" was not used until 1974, when Norio Taniguchi, a researcher at the University of Tokyo, used it to refer to the ability to engineer materials precisely at the nanometer level. Furthermore, at IBM in the United States, a technique called electron beam lithography was used to create nanostructures and devices as small as 40 to 70 nm in the early 1970s.[8] In recognition of the enormous scientific and commercial potential for nanotechnology, President Clinton established the National Nanotechnology Initiative (NNI) in 2000.[9]

ADVENT OF NANOTECHNOLOGY

The invention of scanning tunneling microscope (STM) and atomic force microscope are the achievements that developed nanotechnology through the scientific method rather a than conceptual one. Owing to the invention of scanning tunneling microscope (STM), by Binnig and Rohrer in 1981, it was for the first time that the individual atoms could be easily identified. Some of the limitations of this microscopy were eliminated through the second invention in the series, the atomic force microscope, which could image non-conducting materials such as organic molecules. This invention was integral for the study of carbon buckyballs[10], discovered at Rice University in 1985-1986 and carbon nanotubes few years later.

CREATION OF NANOPRODUCTS:

There are three approaches which aid in development of nanoproducts:

Bottom-up approach

The complex assemblies are made by arranging smaller components. Nanoshells, nanospheres, quantum rods, dendimers liposomes, nanopores, fullerens, nanotubes, nanobelts, nanorings, nanocapsules, and nanowires are some examples of nanoparticles used in dentistry which are produced by bottom up approach.

Top-down approach

In contrast to earlier approach, larger ones are directed in order to create the smaller devices. This is a further miniaturization of the method employed for manufacturing of micron sized particles.

Functional approach

In this approach, components of a desired functionality are developed without regard to their ascending or descending order of assembly & In addition to this, Rice University[12] follows three additional techniques.

Wet nanotechnology

All biological systems are having water as a content like genetic material, membranes, enzymes, and nano-sized cellular components exist mainly in water environment.

Dry nanotechnology

Dry nanotechnology is applicable on physical and surface materials which may be organic or inorganic, for example carbon and silicon. This technology is derived from surface science and physical chemisty, it focuses on fabrication of structure.

Computational nanotechnology

It permits the structuring as well as stimulation of complex nanometric structures. Though the predictive and analytical power of computation is critical to success in nanotechnology, it has a wide range of application involving various fields of medicine and dentistry. It is multidisciplinary owing to its application in diagnostic medicine, drug delivery systems, genetic engineering, surgeries, cosmetic dentistry and many more.

NANOMATERIALS AND NANO DEVICES

The various nanoparticles are

1**. Nanopores** these are simplest medical nanomaterials, surface perforated with holes, or nanopores. These tiny holes allow DNA to pass through one strand at a time and thus making its sequencing more precise. In 1997 Desai and Ferrari created one of the earliest therapeutically useful nonmedical devices, employing bulk micromachining to fabricate tiny cell-containing chambers within single crystalline silicon wafers.

2. **Nanotubes** Carbon nanotubes consist of exclusively carbon atoms arranged in a series of condensed benzene rings rolled-up into tubular architecture. Carbon nanotubes belong to the family of fullerenes, the third allotropic form of carbon, and has been recently developed to use in cancer therapeutics. Being half the diameter of DNA, they detect the presence and pinpoint the location of altered genes.

3. **Quantum dots-** these are the nanomaterials having the unique property of glowing when illuminated with ultraviolet light. These semiconductor nanocrystals ranging from 2 to 10 nm in diameter & possessing tunable targeting properties. Common quantum dots used are cadmium selenide (CdSe), cadmium telluride (CdTe), indium phosphide (InP), indium arsenide (InAs)[13].

4. **Nanoshells-** Unlike carbon fullerenes, nanoshells are dielectric miniscule beads with core of silica and metallic outer layer. Their optical resonance is a function of the relative size of the constituent layers[15]. Halas and West at Rice University in Houston have developed a platform for nanoscale drug delivery in the form of nanoshell[15,16]. They can absorb near infrared light creating intense heat which is lethal to oncocells.

5. **Dendrimers-** Dendrimers were first described by Vogtle et al. They are perfect monodisperse macromolecules with regular and highly branched 3-D architecture. Their branched structures make it possible to ttach drugs and contrast agents to its surface. The emerging role of dendrimers for anticancer therapies and diagnostic imaging has highlighted the advantages of these well-defined materials as the newest class of macromolecular nanoscale delivery devices.[17]

6. **Liposomes-** Liposomes are small artificial spherical vesicles composed of non-toxic phospholipids and cholesterol, which self-associate into bilayers to encapsulate drugs, genes and other biomolecules on aqueous interior. They have peculiar application in drug delivery devices owing to their ability to cross the lipid bilayer and cell membrane. Liposomes are within the size-range of 25 nm to 10 μm. Liposomes of sizes less than 400 nm can rapidly penetrate tumor sites from the blood and are kept in the blood stream by the endothelial wall in healthy tissue vasculature[17].

7. **Nanorods**- Multisegment gold/nickel nanorods are tissue- targeted carriers for grnr delivery into the cell. Nanorods are being explored by Leong's group at Johns Hopkins School of Medicine as a technique that "simultaneously bind compacted DNA plasmids and targeting ligands in a spatially defined manner" and allow "precise control of composition, size and multifunctionality of the gene-delivery system"[15.]

8. **Fullerenes-** They are crystalline particles in form of carbon atoms. The most abundant form of fullerenes is Buckminster fullerenes (C 60) with 60 carbon atoms and arranged in a spherical structure with truncated icosahedron shape, resembles that of a soccer ball (bucky ball), which contains 20 hexagons and 12 pentagons. Other fullerenes are C70, C76, C78, C84, C86, C540 etc.[14]

9. **Nanowires-** Nanowires are glowing silica wires in nanoscale, wrapped around single strand of human hairs. They are about five times smaller than virus and several times stronger than spider silk[18].

10. **Nanospheres-** These are spherical, colloidal nanoscale particles with unique core-shell structure. The inner core of polymeric micelles serves as a nanocontainer for hydrophobic molecules surrounded by an outer shell of hydrophilic flexible tethered strands of polymers[19]. The outer hydrophilic layer forms a stable dispersion in aqueous media, which can be administered intravenously whereas the hydrophobic core and the micelle core acts as a drug reservoir. They have demonstrated high durability in the blood stream and effective tumor accumulation on systemic administration[19-20].

NANOROBOTS:

A technology of creating machines or robots at or close to microscopic scale of nanometers is known as nanorobotics. According to nanorobotic theory "nanorobots are microscopic in size, it would probably be necessary for very large number of them to work together to perform microscopic tasks".

These nanorobots are 0.5-3µ in diameter and are constructed of parts with the dimension in the range of 1-100nm. The main element used is carbon in the form of diamond/fullerene nanocomposites due to its increased strength and chemical inertness. Other light elements such as oxygen and nitrogen can be used for the specific purposes. Externally passive diamond coating provides smooth, flawless coating and evokes less reaction from the body's immune system. They accumulate their energy by metabolizing local glucose, oxygen and acoustic energy[15].

ELEMENTS OF NANOROBOTS

The principal element that comprises the bulk of a medical nanorobot is carbon in the form of diamond or diamondoid/fullerene nanocomposites. Many other light elements such as hydrogen, sulfur, oxygen, nitrogen, fluorine, silicon are used for special purposes in nanoscale gears and other components. Several experimental studies have already proved the chemical inertness of diamond[14]. Medical nanorobots can be of great importance in easy and accurate diagonosis and correction of genetic defects, and help to ensure a greatly expanded health span. Theorotically, they might be used to enhance natural human capabilities other than their role in treatment of diabetes and cancer.

APPLICATION OF NANOROBOTS IN ORTHODONTICS

Recently, the unprecedented progress in treatment modalities have been witnessed in the field of orthodontics, the self ligating brackets, customized treatment techniques, and Invisalign, to name the few[26]. Although the evolution of orthodontic materials in the past 5 decades has been a unique progress curve characterized by periods of intense activity with many developments followed by long quiescent intervals an example being the acid-etching technique, which was introduced in the mid 1950s and became universally accepted in the 1960s. It took more than a decade for this practice to become standard procedure in orthodontics on a large scale. Nanoparticles have recently channelized their way in Orthodontics in various modalities like bracketless tooth repositioning, nanocoated orthodontic wires to reduce friction and also by alveolar tissue augmentation. 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[27].

Orthodontic nanorobots could directly manipulate the periodontal tissues, including gingival, periodontal ligament, cementum and alveolar bone, allowing rapid and painless tooth straightening, rotating and vertical repositioning within minutes to hours.[10] It is seen that nano-filled composites has better marginal seal in enamel & dentin comparable to total acid-etch adhesives and thus aid in enhanced bonding of brackets to tooth structure[25].

Sliding a tooth along an archwire involves a frictional type of force that resist their 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 wires with inorganic fullerenes-like tungsten disulfide nanoparticles (IF-WS_2) which are known for their excellent lubrication properties thus enhancing the efficacy of sliding mechanics[26].

OTHER APPLICATIONS

1. Nature analogue reconstruction
2. Surface engineered dental implant
3. Calcium phosphate for bone augmentation
4. Remineralization with nanoparticles

ARE NANOROBOTS SAFE?

Nanorobots release inhibitors, antagonist or down regulators for pyrogenic pathway in targeted fashion to selectively absorb endogenous pyrogens, chemically modify them & then release back into the body in a harmless inactivated form. The nonpyrogenic nanorobots used in vivo are bulk teflon, carbon powder and monocrystal sapphire. Pyrogenic nanorobots are alumina, silica and trace elements like copper and zinc.

CHALLENGES IN NANODENTISTRY

1. Biocompatibilty
2. Precision in assembly positioning.
3. Coordination in the activities of large numbers of independent micron-scale robots.
4. Economical nanorobot mass production technique.
5. Social issues like public acceptance, ethics, regulation & human safety.

CONCLUSION

The multidisciplinary field of nanotechnology is bringing the science of the almost incomprehensibly small device closer and closer to reality. Nanomaterials and nanoparticles are cornerstones of innovative dental devices used for drug discovery and delivery, discovery of biomarkers, and molecular diagnostics. Expanded utilization of nanotechnology can be envisioned in future for the improvement of public health. It will open a huge range of opportunities of benefit for general practioners, dentist and most importantly the patient.

REFERERNCES

1. Kanaparthy R, Kanaparthy A. The changing face of dentistry: nanotechnology.International Journal of Nanomedicine. 2011;6: 2799–2804.
2. Maheshwari S, Verma SK, Tariq M, Prabhat KC, Kumar S. Emerging trends in oral health profession: The molecular dentistry. Biology and Medicine, 2010; 2 (4): 56-63.
3. Hernández JF, Pérez MA, Valenzuela MCS.Use of new technologies in dentistry.RevistaOdontológica Mexicana. 2011;15 (3): 158-163.
4. Rybachuk AV, Chekman IS, Nebesna NY. Nanotechnology and nanoparticles in dentistry.Pharmacology and Pharmaceutics. 2009;1: 18-21.
5. Sararvana RK, Vijayalakshmi R. Nanotechnology in dentistry. Ind J Dent Res. 2006; 17(2): 62-65.
6. Pal D, Nayak AK. Nanotechnology for Targeted Delivery in Cancer Therapeutics.International Journal of Pharmaceutical Sciences Review and Research. 2010;1(1):1-7.
7. Satyanarayana and Rai: Nanotechnology – The future.Journal of Interdisciplinary Dentistry. 2011;1 (2):93-100.
8. Rocco Castoro, Think Small. U F expects big things fromthe science of small, nanotechnology // The POST 2005; 2;25-27.
9. Sahoo SK, Parveen S, Panda JJ. The present and future of nanotechnologyin human health care. Nanomedicine: Nanotechnology, Biology, and Medicine.2007;3:20–31.
10. Bondor K, Trickland J. How nanotechnology works. Available from:http://wwwhowstuffworks.com.[Last accessed on 2007].
11. Freitas R. Nanodentistry. JADA 2000; 131 : 1559-65.
12. Smalley RE. Institute for nanoscale science and technology. Availablefrom: http://www.media.rice.edu/media/News [Last accessed on2010 Jun 21].
13. Bawarski WE, Chidlowsky E, Bharali DJ, Mousa SA, Emerging nano pharmaceuticals, Nanomed:Nanotech Biol Med, 2008;8:273-82.
14. Meheta RM, Thakral S, Fullerenes: An introduction and overview of their biological properties, Indian J Pharm Sci, 68(1), 2006, 13-9.
15. West JL, Halas NJ: Curr. Opin. Biotechnol. 2000; 11: 215.
16. Sershen SR, Westcott SL, Halas NJ, West JL: J. Biomed. Mater. Res. 2000; 51: 293.
17. Arayne MS, Sultana N, Qureshi F, Nanoparticles in drug delivery of cardiovascular drugs, Pak J Pharm Sci, 20(4), 2007, 340-8.
18. Sing J, Tremendous potential for cancer treatment: Nanotechnology, The Indian Pharmacist, 8, 2008, 23-26.
19. Kataoka K, Harada A, Nagasaki Y, Block copolymer micelles for drug delivery: design, characterization and biological significance, Adv Drug Deliv Rev, 43, 2001, 113-31.
20. Nishiyama N, Kataoka K, Current state, achievements and future prospects of polymeric micelles as nanocarriers for drug and gene delivery, Pharmacol Ther, 112, 2006, 630-48.
21. Fisher, B. (2008). "Biological Research in the Evolution of Cancer Surgery: A Personal Perspective". Cancer Research 68 (24): 10007–10020. 3. Cavalcanti, A., Shirinzadeh, B., Zhang, M. & Kretly, L.C. (2008). "Nanorobot Hardware Architecture for Medical Defense". Sensors 8 (5):2932–2958.
22. Hill, C., Amodeo, A Joseph, J.V. & Patel, H.R.H. (2008). "Nano- and microrobotics: how far is the reality?". Expert Review of Anticancer Therapy 8 (12): 1891–1897.
23. Martel, S., Mohammadi, M., Felfoul, O., Lu, Z. & Pouponneau P. (2009). "Flagellated Magnetotactic Bacteria as Controlled MRItrackable Propulsion and Steering Systems for Medical Nanorobots Operating in the Human Microvasculature". International Journal of Robotics Research 28 (4): 571–582.
24. Cavalcanti, A. (2009). "Nanorobot Invention and Linux: The Open Technology Factor - An Open Letter to UNO General Secretary". CANNXS Project 1.
25. Pai SS, Nagendra A, Pai. AS, Neelima K. Evaluation of a New Nano-filled Bonding Agent for Binding Orthodontic Brackets as comparable to Conventional Bonding Agent: An in-vitro study. J Ind Orthod Society. 2012:46(4):329-333.
26. Eliades T. Orthodontic materials research and applications: Part 1. Current status and projected future developments in bonding and adhesives. American Journal of Orthodontics and Dentofacial Orthopedics. 2006;130(14):445-451.
27. Aeran H., Kumar V., Uniyal S., Tanwer P. Nanodentistry: Is Just A Fiction or Future. J oral Biol Craniofac Res. (2015)., http://dx.doi.org/10.1016/j.jobcr.2015.06.012