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Dentistry at the Nano Level: The Advent of Nanodentistry

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ABSTRACT

One of the revolutions in the filed of dentistry is nanodentistry. It has the power to completely revolutionized the field of dentistry through use of nano particles that shall guide and help maintain one's overall oral health. Painful procedures shall be a thing of the past as nanomaterials shall reduce pain during various dental procedures, help remineralise tooth and associated structures and help maintain oral hygiene. This review focusses on the various aspects of nanodentistry and how it can revolutionize dentistry.

KEYWORDS: Nanoscience, Nanomaterials, Nanorobots

INTRODUCTION

The entire dental fraternity is witnessing the beginning of a truly ground breaking advancement- "Nanodentistry"; which is a rare opportunity. Described in simple terms, it implies engineering at the molecular scale.[1] Nano is derived from the Greek word "nano" which means dwarf and a nanometer is 10–9 meter, or one-billionth of a meter. Since it is difficult to visualise the scale of a nanometer, it might be helpful to compare the scale with objects of appreciable dimensions. If the height of an average human being were scaled from the stretch from the earth to the moon, then each person's atom would be about the size of a baseball (approx. 10 cms in diameter). A nanometer would then be about five baseballs in a row.[2]

As properties of dental materials often significantly change following the micro-to-nano shift, a new field was born to explain these rather strange phenomenon, named nanoscience; the application of its discoveries is dentistry being known as "nanodentistry".[3] Using nanocharacterization tools, a variety of oral diseases can be understood at the molecular and cellular levels and thereby be prevented. Nano-enabled technologies thus provides an alternative and superior approach to assess the onset and/or progression of diseases, to identify targets for treatment interventions as well as the ability to design more biocompatible, microbe resistant dental materials and implants benefitting the entire human race.

Many hopes are pinned on nanodentistry that it will likewise bring tangible benefits to dentistry, from diagnosis to the clinical level.[3] This review stands in favour of the fact that the upcoming methodologies in dental sciences shall be substituted with finer, more precise and sensitive treatment techniques by the application of nanodentistry.

HISTORY OF NANODENTISTRY

The history background of nanotechnology is blotted with a certain amount of skepticism among scholars. Some researchers believe that this is a brand new form of scientific evolution that did not develop until the late 1980s or early 1990s; while others have found evidence that the history of nanotechnology can be traced back to the year 1959. Interestingly, other researchers hold the belief that humans have unknowingly used practical nanotechnological methods for thousands of years (e.g. making steel, paintings and in vulcanization of rubber).[4]

1867:- The first mention of some of the early and distinguishing concepts in nanotechnology (but predating use of that name) was in 1867 by James

Clerk Maxwell when he proposed through a thought experiment that a tiny entity known as Maxwell's Demon shall be able to handle individual molecules in the future.[4]

1914:- The first observations and size measurements of nano-particles was made during the first decade of the 20th century mostly associated with Richard Adolf Zsigmondy, who made a detailed study of gold sols and other nanomaterials with sizes down to 10 nm or less.[4] He was also the first person who used the term "nanometer" explicitly for characterizing the size of a particle and determined it as 1/1,000,000 of millimeter. The credit for developing the first system of classification based on particle size in the nanometer range can be attributed to him.[5]

1959:- The topic of nanotechnology was again touched by the talk- "There's Plenty of Room at the Bottom," given by the Nobel prize winning physicist Prof. Richard Feynman at an American Physical Society meeting at Caltech on December 29, 1959.[6] Prof. Feynman described atomic scale fabrication of nanomaterials using a bottom-up approach, as opposed to the top-down approach that manufacturers we are accustomed to at that time.[4] He suggested nanomachines, nanorobots and nanodevices ultimately could be used to develop a wide range of atomically precise microscopic instruments and manufacturing tools and concluded his lecture by saying these often quoted lines on nanoscience- *"This is a development which I think cannot be avoided."*

1974:- The word assigned to scientific advancement at the nano level is documented to have come from an article that was released in 1974 written from the Tokyo Science University. There, a student, Norio Taniguchi, coined the term "nanotechnology" in his article and the name gained popularity from then on. [4,7]

1977:– Many researchers agree to the fact that the term "Nanotechnology" was coined by Prof. Kerie E. Drexler, a lecturer and researcher at MIT (Massachuehettes Institute of Technology).[8] Researchers claim that that Prof. Drexler also introduced molecular nanotechnology concepts in the late 1970's, which he researched during his tenure at MIT.

NANODENTISTRY AND ITS APPLICATION

Nanodentistry shall make the maintenance of near-perfect oral health through the use of nanomaterials, biotechnology (including tissue engineering), and nanorobotics. Trends in oral health and disease may change the focus on specific diagnostic and treatment modalities because of this technology.

According to Baum BJ,[9] the three main components of nanodentistry are:-

1. Nanomaterials
2. Biotechnology (including tissue engineering)
3. Nanorobotics

STATE OF THE FIELD OF NANODENTISTRY AT PRESENT:-[10,11]

Nanostructures that are in use at present are:-

1. Nanopores: They are tiny holes that allow DNA to pass through, one strand at a time and will make DNA sequencing more efficient. The size of the pores are so minute that separation of DNA might be attempted using this structure(s). As DNA passes through a nanopore, researchers can monitor the shape and electrical properties of each base, or letter on the strand and this can be used to decipher the encoded information in it, including discrepancies in the code known to be associated with cancer and/or other dental anomalies/diseases.[12]

2. Nanotubes: They are most common structures made of carbon atoms bonded into honeycomb-like shapes with enormous strength and electrical conductivity. These are carbon rods about half the diameter of a molecule of DNA that not only can detect the presence of altered genes, but may help researchers pinpoint the exact location of those changes. It helps to identify DNA changes associated with cancer.[13]

3. Quantum dots: They are miniscule molecules making up tiny crystals that glow when stimulated through UV light (of varying wavelengths) and are used to detectabsor cancer. Latex beads are filled with these crystals and are designed to bind to specific DNA sequences. By combining different sized quantum dots within a single bead, scientists can create probes that release distinct colours and intensities of light. When the crystals are stimulated by UV light, each bead emits light that serves as a sort of spectral bar code, identifying a particular region of DNA. To detect cancer, scientists can design quantum dots that bind to sequences of DNA that are associated with the disease. When the quantum dots are stimulated with light, they emit their unique bar codes, or labels, making the critical, cancer associated DNA sequences visible. [12,14]

4. Nanoshells: These are miniscule beads that are coated with gold. By manipulating the thickness of layers that make the nanoshells, scientists can design these beads to absorb specific wavelengths of light. The most useful nanoshells are those that absorb near-infrared light, which can easily penetrate several centimeters of human tissue. UV light absorbed by the nanoshells creates localised heat which is intense and is lethal to cells. Researchers can already link nanoshells to antibodies that recognise cancer cells. Scientists envision letting these nanoshells seek out their cancerous targets, then applying neainfrared light. In laboratory cultures, the heat generated by the light-absorbing nanoshells has successfully killed tumor cells while leaving neighbouring cells intact. [15,16]

5. Dendrimer: These are man-made molecules about the size of an average protein, and have a branching shape. This shape gives them a vast amount of surface area to which scientists can attach therapeutic agents or other biologically active molecules. Dendrimers are formed nanometer by nanometer, so the number of synthetic steps or generations dictates the exact size of particles in a batch. A dense field of molecular groups that serve as hooks for attachment of useful molecules, such as DNA is formed in a peripheral layer. Upon entering a living cell, dendrimers of a certain size trigger a process called endocytosis in which the cell's outer membrane deforms into a tiny bubble or vesicle. The vesicle encloses the dendrimer which is admitted into the cell's interior. Once inside the cell, DNA is released and migrates to the nucleus where it becomes part of cell's genome. It has been used in mammalian cell types and to be used in humans. An example is when Donald et al. reported using glycodendrimer "nanodecoys" to trap and deactivate influenza virus particles.[16]

6. Nanobelt: They have advantages over nanotubes in terms of price, flexibility and practicality. For making nanobelts, oxide is evaporated for 2 hours. The oxide contains zinc, tin, cadmium, gallium or indium. A Nanobelt is deposited as a wool like product and the little straps have a rectangular cross section, with a width of 30-300 nm and a thickness of 10-15 nm and each belt is a single crystal. Because the material is already an oxide, it does not undergo a chemical reaction and has a pure, flawless surface. To mainly differentiate between nanotubes and nanobelts, the lengh of nanotubes are a few millionths of a meter long, while the nanobelts are millimeters long. Also, while nanotubes are made of pure carbon, belts have been made from five oxides.[16]

TECHNIQUES APPLIED IN NANODENTISTRY

Nanodentistry employs two main techniques namely:-[17]

a). Bottom up Technique.

b). Top Down Technique.

A). BOTTOM UP TECHNIQUE:

This technique seeks to arrange smaller components into a more complex assembly.[17]

Nanodentistry as a bottom up approach (procedures using bottom up technique) :-

The dental procedures employed are:-

1. Local anaesthesia
2. Hypersensitivity cure
3. Nanorobotic dentrifice (dentifrobots)
4. Dental durability and cosmetics
5. Orthodontic treatment
6. Photosensitizers and carriers
7. Diagnosis of oral cancer (nanodiagnosis)[7]

B). TOP DOWN TECHNIQUE:

This technique seeks to create smaller devices by using larger ones to direct their assembly.

Nanodentistry as a top down approach (procedures using top down technique):-

The dental procedures employed are:-

- Nanocomposites.
- Nano Light-Curing Glass Ionomer Restorative.
- Nano Impression Materials.
- Nano-Composite Denture Teeth.
- Nanosolutions.
- Nanoencapsulation.
- Plasma Laser application.

• Prosthetic Implants.
• Nanoneedles.
• Bone replacement materials.[2]

NANOFORESIGHT

Nanodentistry will make possible the maintenance of comprehensive oral health by employing nanomaterials, biotechnology including tissue engineering, and, ultimately, dental nanorobotics (nanomedicine).[9] When the first micron-size dental nanorobots will be constructed in 10-20 years, these devices will allow, precisely controlled oral analgesia, dentition replacement therapy using biologically autologous whole replacement teeth manufactured during a single office visit, and rapid nanometer-scale precision restorative dentistry. New treatment opportunities may include dentition renaturalization, permanent hypersensitivity cure, complete orthodontic realignments during a single office visit, convalently - bonded and continuous oral health maintenance using mechanical dentifrobots. Freitas has described that how medical nanorobots might utilize specific motility mechanisms to crawl or swim through human body tissues doing mobile cell surgery carrying oxygen (Nano Respirocyte) 236 times more efficiently as compared to RBCs with navigational precision, acquire energy, sense and manipulate their surroundings, achieve safe cytopenetration (e.g., pass through plasma membranes such as the odontoblastic process without disrupting the cell),and employ any of a multitude of techniques to monitor, interrupt, or alter nerve impulse traffic in individual nerve cells, in real time. The functions of these nanorobots may be controlled by an onboard nanocomputer that executes pre-programmed instructions that are in response to local stimuli that are picked up by its sensors. Also, the dental operator may issue specific instructions by transmitting his orders through acoustic signals to nanorobots present in vivo.[18]

One of the most common procedures in dentistry is the injection of local anesthesia, which has varying degrees of efficacy, patient discomfort and infrequent complications. To induce oral anesthesia in the era of nanodentistry, a colloidal suspension containing millions of active analgesic micron - size dental nanorobots will be instilled on the patient's gingivae. After contacting the surface of the crown or mucosa, the nanorobots shall reach the dentin by migrating into the gingival sulcus and passing painlessly through the lamina propria or 1 - 3 micron thick layer of loose tissue at the cemento -dentinal junction. After reaching the dentin, the nanorobots shall enter dentinal tubules sized 1 - 4 micron in diameter and slowly proceed towards the pulp, guided by a combination of temperature differentials, chemical gradients, specific and controlled positional navigation, all under the onboard nanocomputer control.[13] Treatment options using nanodentistry may include techniques used to repair major tooth defects and dentition renaturalization procedures Renaturalization of dentition shall begin with patients desiring to have their old dental amalgam restoration(s) excavated and their teeth rebuilt with biological materials that mimic real tooth structure in terms of colour and hardeness.[19]

Dentin hypersensitivity is a pathologic phenomenon that may be amenable to a nanodental cure. This etiology(changes in pressure transmitted hydrodynamically to the pulp) is suggested by the finding that hypersensitive teeth have 8 times higher surface density of dentinal tubules; and affected tubules are with diameters twice as large than non-sensitive teeth. A wide availability of Over The Counter (OTC) drugs are available for the treatment of this common painful condition which provides temporary relief. In this particular case, dental nanorobots shall play a reconstructive role and shall selectively and precisely occlude selected pain causing tubules in minutes, offering patients a quick and permanent cure for their ailment.[20]

Orthodontic nanorobots could directly manipulate the periodontal tissues including gingiva, periodontal ligament, cementum and alveolar bone, allowing rapid painless tooth straightening, rotating, and vertical repositioning in minutes to hours, in contrast to current molar uprighting techniques which require weeks or months to proceed to completion.[21]

Effective prevention has reduced caries in children and a caries vaccine may soon be available, but a subocclusal dwelling nanorobotic dentifrice delivered by mouthwash or toothpaste could patrol all supragingival and subgingival surfaces at least once a day, metabolizing trapped organic matter into harmless and odorless vapors and performing continuous calculus debridement.[22]

Dentifrobots would also provide a continuous barrier to halitosis, since bacterial putrefaction is the central metabolic process involved in oral malodor. With this kind of daily dental care available from an early age, conventional tooth decay and gum disease will disappear into the annals of medical history.[20]

Private and public research efforts worldwide are developing nanoproducts aimed at improving health care and advancing medical research. Three applications of nanotechnology are particularly suited to biomedicine: diagnostic techniques, drugs, and prostheses and implants. Interest is also booming in biomedical applications for use outside the body, such as diagnostic sensors and "lab on-a-chip" techniques, which are suitable for analyzing blood and other samples, and for inclusion in analytical instruments for R&D on new drugs. For inside the body, many companies are developing nanotechnology applications for anticancer drugs, implanted insulin pumps, and gene therapy. ABI 007 is 130 nm long and consists of an engineered protein -stabilized nanoparticle that contains paclitaxel, which is used to treat breast, bladder, and more than a dozen other cancers. Such new delivery systems combine a drug with an artificial vector that can enter the body and move in it like a virus. If more advanced clinical tests are successful, ABI-007 is likely to enter the market in a few years. A project on nanotube based electronics biosensors is under process to develop a novel sensor technology platform based on carbon nanotube electronic sensor device, which could be integrated into a biochip and used for detection and analysis of biomolecules in samples from blood, saliva and other body fluids, as well as studies of protein - protein, and protein - small molecule interactions in the research laboratory.

Nanotechnology is also being used to create a new family of "smart" orthopedic and dental implant coating materials that enhance new bone formation over exiting implants. "Smart" coating materials are necessary to selectively increase bone cell function while, at the same time, inhibit functions of competitive cells that lead to soft, instead of bony, tissue formation. Such osseointegration provides mechanical stability to an implant in situ, minimizes motion- induced damage to surrounding tissues, and is imperative for the clinical success of bone implants. Increased bonding between an implant and juxtaposed bone so that a patient who has received joint or dental replacement surgery may quickly return to a normal active lifestyle.

BARRIERS TO OVERCOME

The field of nanotechnology has certain barriers to overcome, if it wants to become a success in the future. These are-

• Precise positioning and assembly of molecular scale part.
• Economical nanorobot mass production technique.
• Simultaneous coordination of activities of large numbers of independent micron scale robots.
• Biocompatibility issues.
• Funding and strategic issues.
• Insufficient integration of clinical research.
• Inefficient translation of concept to product because of inadequate venture capital, excessive bureaucracy and lack of medical input.
• Social issues of public acceptance, ethics, regulation and human safety.[22]

PROBLEMS FOR RESEARCH IN NANOTECHNOLOGY IN INDIA

•Painfully slow strategic decisions
•Sub-optimal funding
•Lack of engagement of private enterprises
•Problem of retention of trained manpower.10

CONCLUSION

Nanodentistry faces numerous critical difficulties in bringing its promises to realization. However, once the initial barriers are crossed and the production of nanoparticles in done on a large scale, it shall be of great benefit to the society and heal reduce the global burden that oral diseases carry.

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