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Research paper

Nanotechnology - the Future Dental Specialization

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Abstract

Nanoscience can be designed to suit the needs of the people and the technology driven by this technology has the potential to improve the state of the developing world. Nanotechnology driven mechanics will become a reality once it is affordable and is accessible to every clinician. Microscale robots that are programmable and controllable allows humans to execute at the cellular and subcellular levels. The application of nanomaterials in dentistry has extended from nano-drug delivery to precision dentistry. With the demand for precision in dentistry, the nanomaterials have been a boon for the upcoming dentists. Nanomaterials have provided better strength, adhesion, resistance to decay, increases life and provides excellent color match in dental restorations. They have furnished better material property for regenerative materials used as bone substitutes.
Nanomaterials have also been used for diagnosis of oral pathologies and have provided surgical precision instruments. However, there are drawbacks to its use; that it can produce nanowastes that can accumulate and can result in unwanted environmental hazards. However, with the emerging need for future useful technology, this branch is gaining popularity and can overcome the problems and can provide a better future.

Keywords: *Nanodrug; nanomaterials; nanometer; nanorobots; nanoscience.*

1. Introduction

Nanotechnology or nanoscience applies to the control of matter at molecular and atomic scale. Developing the structures of 100nm or smaller is involved in this technology. The word nanotechnology is derived from the Greek Nano "nano" or in latin "nanus" meaning dwarf (signifies a billionth of a meter which is the unit of measurement in the field of nanotechnology). 1 nm = 1/ 1000,000,000 of a meter. A human hair measures 50,000 nm, the measure of the bacterial cell is few hundred nanometer. The human eye can see about 10,000 nm in size unaided [1]. Another way to describe nanometer (nm) is concerning relative sizes. When we measure materials in the scale of humans by shrinking them at 1000x it reduces to the size of a fruit fly when we further shrink them to 2000x then it describes the nanoscale.

Prof. Kerie E. Drexler coined the term 'nanotechnology' in the year 1980's. He stated that when we manipulate materials at nanoscale then it is nanotechnology [2]. In a talk by Richard P. Feynman a renowned physicist on "There is Plenty of Room at the Bottom" speculated the potential of nanosized devices and this has resulted in his vision of nanotechnology [3]. The construction of functional structure using individual atoms and molecules is the idea behind nanotechnology. This molecular structure has a complete control at this nanoscale dimension. Simply put, manipulating matter atom by atom is nanotech [3]. This technology can achieve the arrangement of the atoms as desired to achieve efficiencies.

Nanotechnology helps to establish a link of nanoscopic and macroscopic universes [4]. Nano-particles bestows unique features due to their small size [5]. It is translated as "the science of the small" [6]. In addition of creating the small sized materials it is involved in the development of materials, not only with different biological properties but also physical and chemical properties [2].

Present researches have been directed towards the production of nanoscale structures. There are many different approaches followed for the creation of nanoproducts; the most common approaches are bottom-up, top-down and functional approaches [7].

2. Nanotechnology in restorative dentistry

2.1 Nanocomposites and Nanoionomer

The Bowen's Bis-GMA {2, 2-bis [4-(2-hydroxy-3-methacryloxypropoxy) phenyl]-propane} revolutionized the modern dental composite era. The polymerization of the organic matrix occurs by light this is promoted by the synthetic polymers, inorganic fillers, initiators and activators and all are bonded together by silane coupling agents.
In the composite restorative market it is bound to find several nanocomposites materials. Typically 3 composites with different composition and nanofillers are: The Filtek Supreme, Premise and the nanocomposites.
The Filtek Supreme (3M ESPE, St Paul, MN, USA) composite material has (Nanomers) and nanoclusters (NCs).
Silica particles that are monodispersed non-aggregated and non-agglomerated having a diameter of 20 to 75nm make up the Nanomers. Loosely bound aggregates of nanosized particles are Nanoclusters.
There are 2 types of Nanoclusters.
a. One of them is the zirconia-silica particles formed by silica and zirconyl salt colloidal solution. The size of the particles of the cluster is between 2-20 nm.

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b. NC fillers of second type is synthesized from a particle size of 75-nm of silica. Treating with 3 methacryloxypropyltrimethoxysilane (MPTS), helps to prevent aggregation [8].
Premise (Kerr/Sybron, Orange, CA, USA) also named as Point 4 due to the average particle size of 0.4 μm, is a second commercial product that is nanohybrid containing non-agglomerated "discrete" silica nanoparticles, prepolymerized fillers (PPF), and glass fillers. It has about 90% of the particles that are smaller than 0.8 μm. The nanoparticles provide a smooth and round edge. The smooth edges uniformly distributes the stress around it [9].
Ceram-X is a third commercially available composite material. It is a nano-ceramic composite containing ormocer. This material contains glass fillers (1.1-1.5 μm), it differs from conventional hybrid as it contains: Nanofillers of 10 nm. It substitutes the micro fillers that is commonly used in hybrid composites (agglomerates of silicon dioxide particles). These nano-ceramic particles are a conglomerate of the inorganic-organic composite particles and the polymerization occurs by the methacrylate group in nanoceramics and nanofillers [10].
There is increased filler loading provided by the Nanocomposites that reduces the resin matrix, this reduces the polymerization shrinkage and increases the esthetics and strength. Addition of reinforcing fillers with nano-fibers strengthens the nanocomposites. The nanocomposites release the calcium and fluoride ions decreasing the incidence of dental caries. There has been improvement in dental materials and their clinical application due to the nanocomposites. The properties of the nanocomposites can be improved even further due to the flexible technology such as nanotechnology.

3. Nanotechnology in Periodontology and oral and maxillofacial surgery

Bone is a natural nanostructure containing pores of at least 100nm in dimension and also consisting of a composite material of organic collagen and inorganic hydroxyapatite (HA) and is highly biocompatible. In dentistry hydroxyapatite has been introduced in many forms and are being used as filling material for bone defects. But Hydroxyapatite does not completely degrade. The new bone formation can be seen between the spaces of the graft material. The remaining graft material can hinder the complete healing of the bone [11]. Xenografts have been successfully used in oral and maxillofacial surgeries, implant surgeries and periodontology. There has been a concern of this bone graft of disease transmission.
The natural nanostructure of the bone can be emulated by nanotechnology and can be used in dental materials [12]. Recently introduced nano-hydroxyapatite (nHA) is a material that is highly biocompatible and biodegradable. Nanoparticulate bone have smaller particle size. This small particle size will have larger surface area and the volume. The bone crystallites exhibit a loose microstructure due to the nanopores existing between them. The cells can grow faster within these nanopores and enables the deposition of the crystals around it.
A value of 60% in Porosity can be seen both in nanomolecules and micromolecular aggregations. The nanopores are interconnected and the cells can get embedded along with the essential proteins. The surface of the pores are modified in such a way that the silica carries out the function of hanging the protein around it. Here the silica compound is most important [12]. The synthetic nanobone graft have unique feature of osteoinduction, fully synthetic, highly porous, biologically active which enables the graft to be degraded by the osteoclasts and has excellent processability.
The methods for preparation of this material include chemical precipitation, hydrothermal reaction, pyrolysis of aerosol and sol-gel synthesis. The hydroxyapatite structural properties depend on the method of production of the material [13]. Commercially available materials are NanoBone, OSTIM, NANOSS, VITOSS.
Rosette nanotubes are biologically inspired and nanocrystalline hydroxyapatite hydrogel nanocomposites can be used as an improved bone. These Helical rosette nanotubes or also called as HRN are formed by immobilizing chemically 2 DNA base pairs that creates a soft nanomaterial mimicking natural nanostructural component of bone. They are self-assembled and are 3.5 nm in diameter [14]. Nanocrystalline hydroxylapatite is dispersed into these helical rosette nanotubes. It demonstrated improved mechanical properties, increased osteoblast adhesion up to 236% compared to hydroxyapatite, stimulated hydroxyapatite showed mineralization similar to hydroxyapatite/ collagen assembly pattern in natural bone[15].

4. Nanotechnology in implant dentistry

Implant surface quality is based on the
(1) Mechanical
(2) Topographic, and
(3) Physicochemical properties (Albrektsson and Wennerberg [16]
All the surface characteristics are related. Hence when we change one quality, the others are also affected. The observation mentioned by Albrektsson and Wennerberg plays a significant role when we discuss the endosseous titanium implants. The surfaces of these materials at the micro or nano levels have the effect of quantum phenomenon that does not play by the rules of bulk materials. Hence it is challenging to control the surface effects and the charge on the surface of these materials at the level of nanotopography. Though it is challenging it is needed to differentiate specific effects in surface energy or chemical reactivity.
The topography changes on the surface of the implants can be done by molecular self-assembly. The process of molecular self-assembly, self-assembled monolayers or SAMs is by the spontaneous chemical adsorption and close vertical packing onto a substrate that is specifically created, exposing the end chain groups at the interface. Osteoinductive or cell adhesive molecule is the exposed functional end group. There are peptide domains that have been appended to the self-assembled monolayers that are composed of PEG (Polyethylene glycol) and these have been applied to the surface of the titanium [17].
In the physicochemical method, different materials of the implant is treated chemically to expose the material surface and create a nanoscale topography conducive for the attachment of the natural proteins and cells. The method of chemical treatment is very much prevalent among the investigators exploring this category of implant surface characteristics.
The fourth approach is to deposit the nanoparticle onto the implant surface that will create the nanofeatures. Nanometer-scale deposition of calcium phosphate on the surface of the dental implant surface by sol-gel transformation provide a surface characteristic that is better than other types of materials. Titanium, zirconia, hydroxyapatite, silver, gold [18, 19] and other molecules have been tried or hypothesized. This nanoscale deposition of the surface of the dental implants can provide a strong physical attraction to biological substrates [20].

5. Future of nanotechnology in dentistry

5.1 Nanorobotics

1. Inducing anesthesia: One of the most common procedures in dentistry is the injection of local anesthesia. The effect of anesthesia varies, and there are long waits before the effects begin. Complications and discomfort are the other effects of the anesthesia. Transcutaneous electronic stimulation of the nerve, electronic targeted anesthesia, and other transmucosal, intraosseous or topical techniques, shows clinical effectiveness that is limited.
In the era of nanodentistry dental nanorobots will provide active anesthesia. These nanobots will pass through the tooth/mucosa reach the dentin. These nanobots can enter the tubules under the

control of the onboard computer as directed by the dentist. These robots can complete the entire journey in 100 seconds.

The nanorobots used for the reduction of the pain can stop the pain in all the teeth. They can be commanded by the dentists to stop all the sensations. On pressing the sensation button the selected tooth immediately numbs. Later on command, there is reduction and stoppage of the transmission of the stimuli. Once the oral proceedings is completed the nanorobots can be controlled to restore the sensations. These nanorobots can be aspirated once the procedure is completed. This nanorobotic types of controlled anesthesia can be an excellent tool to reduce anxiety and discomfort in patients. [21]

The tubules in dentin have maximum concentration close to the pulpal wall of about 48000, at the midway between the dentinoenamel junction and pulpal wall of about 37000 and about 22000 near the dentinoenamel junction. It is lowest at the root surface of about 13000. These dentinal tubules provide ideal navigation endpoints for the nanobots.

But the disadvantage of this is that these dentinal tubules have diameters that are greater at the pulp region and is narrowest close to the tooth surface. These intricate branching of the dentinal tubules crisscross the intertubular dentin and produces a challenge for the navigation of the nanorobots. Further, the movement of these nanorobots can be hampered by the sclerosed dentin in teeth of older individuals. The dentin can exhibit larger tubules of 10 to 50 micrometer or even more in few of the cases that can afford a comfortable journey of the nanorobots. These nanobots can traverse the complete length of the tubule of about 10 mm at 100 μm/sec in 100 seconds.

The dentists can command the dental nanorobots at every time point after entry into the pulp through the dentinal tubules. Once inside the pulp chamber, the dentist can press the desired icon on the handheld controller display to shut down all the sensations of the desired tooth. It can also be disabled later on command.

2. Dentin Hypersensitivity:

Dentinal hypersensitivity according to the Brännström theory is caused due to the changes in the pressure within the dentinal tubules due to the movement of the fluid within. There is a large number of exposed dentinal tubules on the surface of the dentin in patients having sensitive teeth. There is a large number of therapeutic agents that relieve this condition in the patient. However, these agents only produce temporary relief. Hence to overcome this discomfort reconstructive nanorobots using the native materials to occlude the tubules precisely would provide the patients with quick and permanent cure [22].

3. Nanorobotic dentifrice [dentifrobots]:

Dentifrobots could serve as the tooth patrolling devices that could eliminate the organic deposits and perform calculus elimination. This oral hygiene procedure could be done once in a day, and all trapped harmful metabolites and plaque could be eliminated. These invisibly small dentifrobots [1-10 micron], crawling at 1-10 microns/sec, could be programmed to deactivate on disuse and if swallowed by the patients could be safely eliminated without complications [23].

4. Repair of teeth:

Nanorobotics manufacture and install biologically autologous whole tooth that includes both mineral and cellular components (i.e., complete dentition replacement therapy). It should be feasible within the duration of the office visit. A desktop facility could help in fabricating the new tooth that should be economical and be accessible to the patients within the duration of the office visit. Chen et al. created the enamel by using highly organized microarchitectural units of nanorod-like calcium hydroxyapatite crystals arranged roughly parallel to each other [24].

5. Durability and appearance

Sapphire and diamonds are good alternatives that are 20 to 100 times harder than enamel and have a better flexural strength and also has excellent biocompatibility. Similar to enamel, sapphire is susceptible to acid corrosion to an extent. Sapphire can be manufactured in any color this can provide the added advantage of iridescence. Iridescence is the phenomenon where the sapphire crystals can show different colors on changing the angle of illumination. This will add more value to dental cosmetics. Sapphire and diamond are brittle in its pure state, but nanostructured composite material that possibly includes embedded carbon nanotubes have improved the structure of the material producing higher resistance to corrosion [3].

6. Tooth remineralization

Complete re-mineralization of the tooth could be an addition to the dental practice providing a perfect solution for the esthetic needs of the patients. The trend for removal of the old worn out amalgam has already begun. Nanobots could completely replace the tooth structure using the natural tooth organic materials. However, the demand can also be for full crown replacement of the artificial substitutes [23].

7. Orthodontic realignment:

Mechanical nanobots could straighten the teeth without pain that could allow rapid straightening and repositioning of the teeth. This process of repositioning and realignment could be done in minutes to hours.

5.2 Materials

Dental Impression materials

When the Nanofillers are added into vinylpolysiloxanes, it provides a unique addition. The resultant material has a better flow, improvement in hydrophilic properties with lesser voids at the better model pouring. It also provides an improvement in detail and precise outcome in the final models. The commercially available product is Nanotech elite HD plus®.

5.3 Nanoneedles:

Nanoneedles and nanotweezers are under development. Nanosized stainless-steel crystals are incorporated in these needles and have been developed, and it is commercially available as Sandvik Bioline, RK 91 needles (AB Sandvik, Sweden) [11].

5.4 Nanoencapsulation

The SwRI (South West Research Institute) has developed the nanocapsule delivery system that delivers the vaccines, antibiotics and drug delivery. This nano-delivery system is a targeted drug delivery system and has reduced side effects. The institute also develops protective clothing and filtration masks that are antipathogenic.

The research by the institute on wound healing using Nanocrystalline silver particles embedded in wound dressings provide instantaneous healing of the wounds. The calcium phosphate-based nanocarriers are readily flowable, mouldable paste conforms and interdigitate to integrate with the host bone.

Hepatitis B virus envelope L hollow nanoparticle has been used for targeted drug delivery by a team of scientist from Osaka University, Japan in 2003. This nanoparticle could enter the liver to deliver the required gene. This can deliver gene and drugs to the required site. In dentistry, nanoparticles could be engineered to treat the disease of the periodontium.

5.5 Nano sterilizing solution

Ecotru® disinfectant is a revolutionary nanotechnology-based solution. It works on a super science of nanoemulsion technology. It uses nanosized emulsifier droplets of oils. This has nanoparticles that are antimicrobial. They are harmless and protective of any working surfaces.

5.6 Nanotweezers:

These micrometer scale electromechanical tweezers have been fabricated with silicon (Mc Donald et al. 2000). The arms are produced by tungsten deposition (200 µm long and 2.5µm wide) that can be closed by applying an electrical potential. These nanotweezers are ideal for holding the tissues during surgery. They can also be used to manipulate bacteria, viruses. They can be used for measurement of biochemical activity. During surgery, they can be used for the separation of different types of vital and non-vital cells. In the separation of breast cancer cells from normal T-lymphocytes, carcinoma cells from blood cell components these tweezers are useful. [25]

5.7. Nanoscissors

The nanoscissors are used to cut and reassemble DNA strands. This can help in the reconstruction of new DNA assembly. Thus cutting and reassembling of the DNA strand is a procedure followed in recombinant DNA technology. Nanoscissors can also be used for precision surgeries of cancer and other complicated surgeries. The instrument was developed by a mechanical engineer Adela ben Yakar in 2006. The scissors are 3 nm (Takuzo Aida et al. 2007).
The nanoscissors uses a photo-responsive chemical group like a molecular machine. It extends or folds when contacting different wavelength of incident light. Intermittent photon excitation or multiphoton excitation can be used for rapid movement of the scissors. These scissors require two types of wavelength one of visible light and the other UV light. When the scissors are exposed to the UV-light and the visible light alternately the length of the handles reduces and increases. This will drive the scissors to open close motion.
The blades of the scissor contain the zinc porphyrin that can bind with the nitrogen-containing molecules of the DNA. The porphyrin can help to hold the host DNA during the closing and opening of the blades of the scissors. The Ben Yaker group have worked on nanotechnology to provide groundbreaking instruments that drive the diagnostics and therapeutics in medicine to next level. [26]

6. Conclusion

Nanotechnology in nanomedicine can improve the diagnosis and therapy. It can be a tool for local delivery of the therapeutic drug. The aim of this emerging technology in dentistry is to improve the quality of the dental materials, improve the diagnosis of the disease and develop this technology for the treatment of conditions like dentinal hypersensitivity, dental decay, hypomineralised tooth, fatal conditions like cancer and other oral diseases. Treating the conditions with good ethical and social backing for this kind of technology with a beneficial and therapeutic aim would eliminate all common disease, alleviate pain and suffering.

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