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Nanotechnology in Dentistry – A Review

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Abstract Dentistry is frequently facing revolutions in order to provide a most reliable and comfortable therapeutic options for the patients. Recently nanotechnology has emerged as a new science exploiting specific phenomena and direct manipulation of materials on nanoscale. Application of nanotechnology in dentistry holds promise for the maintenance of comprehensive dental care by employing nanomaterials including tissue engineering and ultimately nanorobots. This paper highlights the role of nanomaterials and their potential to be used in the diagnosis and management of oral diseases.

Keywords: *nanomaterials, nanodentistry, nanorobots, nanotechnology, nanoscale materials*

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1. Introduction

Nanotechnology is the engineering of functional systems at the molecular scale. It deals with structures ranging in the size of 100 nanometers or smaller in at least one dimension and developing materials or devices within that size. [1] The basic idea of nanotechnology is to employ individual atoms and molecules to construct functional structures. It gives us an understanding of how structures (such as polymers, crystals, drugs, and proteins) are made at a fundamental level (from their atoms up to molecular level) and how their molecular arrangements can be altered to alter the macroscopic properties of a material.

2. Fundamental Concepts of Nanotecnology

Nanoscale materials can be defined as those whose characteristic length scale lies within the nanometric range, i.e in the range between one and several hundreds of nanometers (preferably between 0-100nm). One nanometer (nm) is one billionth or 10^{-9}, of a meter. To put that scale in another context, the comparative size of a nanometer to a meter is the same as that of a marble to the size of the earth. A unique aspect of nanotechnology is the vastly increased ratio of surface area to volume present in many nanoscale materials which opens new possibilities [1].

2.1. The Techniques [2]

2.1.1. Top-down Technique

These seek to create smaller devices by using larger ones to direct their assembly. Here, small features are made by starting with larger materials patterning and carving down to make nanoscale structures in precise patterns. Complex structures containing hundreds of millions of precisely positioned nanostructures can be fabricated. Materials reduced to the nanoscale can suddenly show very different properties, enabling unique applications. As the size of system decreases there is increase in ratio of surface area to volume and number of physical phenomena becomes noticeably pronounced which include statistical as well as quantum mechanical effects.

2.2.2. Bottom-up Technique

These seek to arrange smaller components into more complex assembly. This begins by designing and synthesizing custom made molecules that have the ability to self-assemble or self-organize into higher order mesoscale or macroscale structures. Modern synthetic chemistry has reached the point where it is possible to prepare small molecules to almost any structure. These methods are used today to manufacture a wide variety of useful chemicals such as pharmaceuticals or commercial polymers. Such bottom-up approaches are much cheaper than top-down methods, but could potentially be overwhelmed as the size and complexity of the desired assembly increases.

3. Nanomaterials

Siegel has classified nanomaterials as zero dimensional, one dimensional, two dimensional and three dimensional nanostructures. [3] Various nanostructures include:

Nanoparticles
Nanopores
Nanotubes
Nanorods

Nanospheres
Nanofibres
Nanoshells
Dendrimers & dendritic copolymers.

Inorganic nanoparticles either currently in use or under development include

- Semiconductor nanoparticles
- Metal nanoparticles
- Metal oxide nanoparticles
- Silica nanoparticles
- Polyoxometalates
- Gold nanocrystals

4. Nanomedicine & Nanodentistry

Nanomedicine is the science and technology of diagnosing, treating and preventing disease and traumatic injury relieving pain and preserving and improving human health through the use of nanoscale structured materials, biotechnology and genetic engineering, eventually complex molecular machine systems and nanorobots [4,5].

Nanodentistry will make possible the maintenance of near-perfect oral health through the use of nanomaterials, biotechnology including tissue engineering and nanorobotics.

5. Nanodentistry

Nanodentistry includes:

- Nanorobotics,
- Nanodiagnostics,
- Nanomaterials

5.1. Nanorobotics

5.1.1. Local Anaesthesia

Micron sized active analgesic dental robots suspended in a colloidal solution instilled on the patient's gingiva reach the pulp via the gingival sulcus, lamina propria and dentinal tubules. This is guided by a combination of chemical gradients, temperature differentials and even positional navigation which are all under the control of on board nanocomputer as directed by the dentist.

Assuming a total path length of about 10 mm from the tooth surface to the pulp and a modest travel speed of 100 µm/s, nanorobots can complete the journey into the pulp chamber in approximately 100 seconds.

Once installed in the pulp and having established control over nerve-impulse traffic, the analgesic dental nanorobots maybe commanded by the dentist to shut down all sensitivity in any tooth that requires treatment. When the dentist presses the icon for the desired tooth on the hand-held controller display, the selected tooth immediately numbs. After the oral procedures are completed, the dentist orders the nanorobots (via the same acoustic data links) to restore all sensation, to relinquish control of nerve traffic and to egress from the tooth via similar pathways used for ingress; following this, they are aspirated. Nanorobotic analgesics offer greater patient comfort and reduced anxiety without the use of needles, greater selectivity and controllability of the analgesic effect, fast and completely reversible action, and avoidance of most side effects and complications [4].

5.1.2. Hypersensitivity Cure

Dentin hypersensitivity may be caused by changes in pressure transmitted hydrodynamically to the pulp. This is based on the fact that hypersensitive teeth have 8 times higher surface density of dentinal tubules and tubule diameter twice as larger than non sensitive teeth. Dental nanorobots could selectively and precisely occlude selected tubules in minutes, using native biological materials, offering patients a quick and permanent cure [4].

5.1.3. Dental Biomimetics

The most interesting venue for speculation on the nanorestoration of tooth sturucture is that of nanotechnology mimicking processes that occur in nature (biomimetics), such as the formation of dental enamel. Through an affordable desktop manufacturing facility, fabrication of a new tooth in the dentist's office within the time & economic constraints of a typical dental office visit, complete dentition replacement therapy will become feasible soon.

Chen *et al* utilizing nanotechnology simulated the natural biomineralization process to create the dental enamel, using highly organized microarchitectural units of nanorod-like calcium hydroxyapatite crystals arranged roughly parallel to each other [6].

5.1.4. Dental Durability and Cosmetics

Artificial materials such as sapphire or diamond, which have 20 to 100 times the hardness and failure strength of natural enamel or contemporary ceramic veneers, as well as good biocompatibility are nowadays used to improve the durability & appearance of tooth. Though sapphire is susceptible to acid corrosion, it can be manufactured in virtually any color, offering interesting cosmetic alternatives to standard whitening and sealant procedures. Pure sapphire and diamondare brittle are prone to fracture if sufficient shear forces are imposed, but they can be made more fracture-resistant as part of a nano-structured composite material that possibly includes embedded carbon nanotubes [6].

5.1.5 Orthodontic Treatment

Orthodontic nanorobots could directly manipulate the periodontal tissues, including gingivae, periodontal ligament, cementum and alveolar bone, allowing rapid and painless tooth straightening, rotating and vertical repositioning within minutes to hours. This is in contrast to current molar-uprighting techniques, which require weeks or months to complete [4].

5.1.6. Dentifrobots

Subocclusal dwelling nanorobotic dentifrice delivered by mouthwash or toothpaste could patrol all supragingival and subgingival surfaces atleast once a day, metabolizing trapped organic matter into harmless and odorless vapors and performing continuous calculus debridement.

These invisibly small dentifrobots [1-10 micon], crawling at 1-10 microns/sec, would be inexpensive, purely mechanical devices, that would safely deactivate themselves if swallowed, and would be programmed with strict occlusal avoidance protocol. Properly configured dentifrobots could identify and destroy pathogenic bacteria residing in the plaque and elsewhere, while allowing the ~500 species of harmless oral microflora to flourish in a healthy ecosystem. Dentifrobots also would provide a continuous barrier to halitosis, since bacterial putrefication is the central metabolic process involved in oral malodor [4,7].

5.1.7. Renaturalization Procedures

Dentition renaturalization procedures may become a popular addition to the future dental practice, made possible through esthetic dentistry. This can be mainly used in patients who desire to have their old dental amalgams excavated and their teeth remanufactured with native biological materials. Full coronal renaturalization procedures in which all fillings and crowns are removed, and the affected teeth are remanufactured to become indistinguishable from the original teeth [4].

5.1.8. Nanovectors

Calcium phosphate nano particles was found to potentially serve as a good vehicle (nanovectors) to deliver target genes to fibroblasts for periodontal regenerative purposes in vitro [8].

5.2. Nanodiagnostics (Diagnosis of Oral Cancer & Other Diseases)

5.2.1. Nanoscale Cantilevers

These are flexible beams resembling a row of diving boards that can be engineered to bind to molecules associated with cancer.

5.2.2. Nanopores

These are tiny holes that allow DNA to pass through one strand at a time. They will make DNA sequencing more efficient.

5.2.3. Nanotubes

These are carbon rods about half the diameter of a molecule of DNA that not only can detect the presence of altered genes but also may help researchers pinpoint the exact location of those changes.

5.2.4. Quantum Dots

These are nanomaterials that glow very brightly when illuminated by ultraviolet light. They can be coated with a material that makes the dots attach specifically to the molecules to be tracked. Quantum dots bind themselves to proteins unique to cancer cells, literally bringing tumours to light.

5.2.5. Nano Electromechanical Systems (NEMS)

Nanotechnology based NEMS biosensors that exhibit exquisite sensitivity and specificity for analyte detection, down to single molecule level are being developed. They convert (bio) chemical to electrical signal [9].

5.2.6. Oral fluid nano sensor test (OFNASET)

Oral Fluid NanoSensor Test (OFNASET) technology that combines self-assembled monolayers (SAM), bionanotechnology, cyclic enzymatic amplification, and microfluidics for detection of salivary biomarkers for oral cancer. It was demonstrated that a combination of two salivary proteomic biomarkers (thioredoxin and IL-8) and four salivary mRNA biomarkers (SAT, ODZ, IL-8, and IL-1b) detected oral cancer with high specificity and sensitivity [10].

5.2.7. Optical Nanobiosensor

The nanobiosensor is a unique fiberoptics-based tool which allows the minimally invasive analysis of intracellular components such as cytochrome C, an important protein involved in the production of cellular energy as well as in apoptosis, or programmed cell death [11].

5.2.8. Lab-on-a-chip methods

Lab-on-a-chip (LOC) is a device which integrates several laboratory functions on a single chip. LOCs deal with the handling of extremely small fluid volumes down to less than pico liters.

Assays are performed on chemically sensitized beads populated into etched silicon wafers with embedded fluid handling and optical detection capabilities. Complex assays can be performed with small sample volumes, short analysis times, and markedly reduced reagent costs. LOC methodologies have been used to assess the levels of interleukin-1beta (IL-1beta), C-reactive protein (CRP), and matrix metalloproteinase-8 (MMP-8) in whole saliva, which are potential use of these biomarkers for diagnosing and categorizing the severity and extent of periodontitis [12,13].

5.3. Nanomaterials in Dentistry

5.3.1. Nanocomposites

Non agglomerated discrete nanoparticles are homogeneously distributed in resins or coatings to produce nanocomposites. The nanofiller used includes an aluminosilicate powder having a mean particle size of 80 mm and a 1:4 M ratio of alumina to silica and a refractive index of 1.508 [7].

Advantages:

Superior hardness, flexible strength, modulus of elasticity, translucency, esthetic appeal, excellent colour density, high polish & polish retention & excellent handling properties.

5.3.2. Nanosolution

Nanosolutions produce unique and dispersible nanoparticles, which can be added to various solvents, paints & polymers in which they are dispersed homogenously. Nano technology in bonding agents ensures homogeneity and that the adhesive is perfectly mixed everytime [14].

5.3.3. Esthetic Materials

With the combination of finishing and polishing procedures, a nanotechnology liquid polish application might provide a glossier surface for resin composite restorations.

5.3.4. Nano-optimised Mouldable Ceramics

- Nanofillers - Enhances polishing ability and reduces wear.
- Nanopigments - Adjust the shade of the restoration to the surrounding teeth (chameleon effect).

- Nanomodifiers - Increases the stability of the material and prevent sticking to instruments [15].

5.3.5. Impression Materials

Nanofillers are integrated in vinylpolysiloxanes, producing a unique addition of siloxane impression materials. The material has better flow, improved hydrophilic properties and enhanced detail precision [16].

5.3.6. Nanoencapsulation

SWRI [South West Research Institute] has developed targeted release systems that encompass nanocapsules including novel vaccines, antibiotics and drug delivery with reduced side effects. Future specialized nanoparticles could be engineered to target oral tissues, including cells derived from the periodontium [7].

5.3.7. Other Products Manufactured by SWRI

a. Protective clothing and filtration masks, using anti pathogenic nanoemulsions and nanoparticles

b. Medical appendages for instantaneous healing

- Biodegradable nanofibres - delivery platform for haemostatic
- Wound dressings with silk nanofibres in development
- Nanocrystalline silver particles with antimicrobial properties on wound dressings [Acticoat™, UK] [7]

Silver is an antiseptic, targeting a broad spectrum of $Gram^+$ and $Gram^-$ bacteria such as MRSE, MRSA and even vancomycin-resistant strains. Pure silver particles at nanoscale have greater surface to mass ratio offering greater solubility and chemical reactivity, and higher antibacterial activity compared to conventional silver preparations [17].

c. Bone targeting nano carriers [18]

Calcium phosphate-based biomaterial is an easily flowable, moldable paste that conforms to and interdigitates with host bone supporting growth of cartilage and bone cells.

5.3.8. Materials to Induce Bone growth

Bone is a natural nanostructured composite composed of organic compounds (mainly collagen) reinforced with inorganic ions (HA). It is this natural nanostructure that nanotechnology aims to emulate for dental applications. The smaller the particle size, the larger the surface area in volume. Nanobone uses this principle. The nanocrystallites show a loose microstructure, with nanopores situated between the crystallites. This material structure will be completed by pores in the micrometer area. By following this process, a rough surface area is formed on the boundary layer between the biomaterial and cell, which is very important for fast cell growth. All pores are interconnecting. Because the cells are too big for the small pores, blood plasma containing all the important proteins is retained in the interstices [18].

Hydroxyapatite nanoparticles used to treat bone defects are:

Ostium (Osartis GmbH, Germany) HA

VITOSSO (Orthovita, Inc, USA) HA + TCP

NanOSS™ (Angstrom Medica, USA) HA

Recently developed nano bioactive glass in concentration less than 4mg/ml. was found to be biocompatible with gingival fibroblasts in an in vitro study [19]. Calcium sulphate is used to fill small voids such as those found in post extraction sockets and periodontal bone defects and as an adjunct to the longer lasting bone grafting materials. Dr.Ricci has formulated a new calcium sulphate based nanocomposite. BoneGen-TR which resorbs more slowly and regenerates bone more consistently.

5.3.9. Nanoneedles

Suture needles incorporating nano-sized stainless steel crystals have been developed. Nanotweezers are also under development which will make cell-surgery possible in the near future [7].

Trade name: Sandvik Bioline, RK 91™ needles [AB Sandvik, Sweden].

5.3.10. Self Assembly

It is an autonomous organization of components into patterns or structures without human intervention. Polyelectrolyte materials bearing a number of charged groups are most commonly used in self-assembly as they enable stable, smooth, homogeneous films to be formed with a number of functional groups. Of these the best studied systems are polyallylamine/ polystyrene sulfonate and diazo resin/ polystyrene sulfonate [5,20].

Recently the use of pH-induced self-assembly of a peptide-amphiphile is used to artificially construct a nanostructured fibrous scaffold with the structural features of extracellular matrix. Furthermore, after cross-linking, the newly produced fibers are able to direct mineralization of hydroxyapatite to form a composite material in which the crystallographic axes of hydroxyapatite are aligned with the long axes of the fibers which mimics the periodontium.

5.3.11. Nanomaterials for Periodontal Drug Delivery

Nanomaterials widely explored for controlled drug release are hollow spheres, core-shell structure, nanotubes and nanocomposite. Drugs can be incorporated into nanospheres composed of a biodegradable polymer, and this allows for timed release of the drug as the nanospheres degrade facilitating site-specific drug delivery.

Recently triclosan-loaded nanoparticles prepared using poly (d,l-lactide-coglycolide), poly(d,l-lactide) and cellulose acetate phthalate was found to be effective in achieving reduction of inflammation. [21,22] Tetracycline incorporated into microspheres is available as Arestin for drug delivery by local means into periodontal pocket. [5] A nanostructured 8.5% doxycycline gel was observed to afford periodontal surface preservation following experimental periodontal disease in rats [23].

5.3.12. Photodynamic Therapy

Antimicrobial photodynamic therapy (aPDT) is a new treatment method for the removal of infectious pathogens using a photosensitizer and light of a specific wavelength, e.g., toluidine blue with a wavelength of about 600 nm. Recently, Methylene blue (photo sensitizer) has been encapsulated within poly (D,L lactide – co – glycolide) (PLGA) nanoparticles (≈ 150 – 200nm in diameter) and was found to offer a novel design of nano-platform for enhanced drug delivery and photodestruction of oral biofilms. A new photosensitizer, indocyanine green (ICG)-loaded nanospheres with an 805 nm wavelength low-level diode laser irradiation showed an aPDT-like effect, which might be useful for a potential photodynamic periodontal therapy [24].

5.3.13. Implants

Nanotechnologies are increasingly used for surface modifications of dental implants as surfaces properties such as chemistry and roughness play a determinant role in achieving and maintaining their long-term stability in bone tissue. Direct bone-to-implant contact is desired for a biomechanical anchoring of implants to bone rather than fibrous tissue encapsulation [25].

Recently three nano-structured implant coatings are developed:

- **Nanostructured diamond:** They have ultrahigh hardness, improved toughness over conventional microcrystalline diamond, low friction, and good adhesion to titanium alloys [26].
- **Nanostructured processing applied to hydroxyapatite coatings:** This is used to achieve the desired mechanical characteristics and enhanced surface reactivity and has been found to increase osteoblast adhesion, proliferation, and mineralization [26].
- **Nanostructured metalloceramic coatings:** These provide continuous variation from a nanocrystalline metallic bond at the interface to the hard ceramic bond on the surface [26].

Nanostructured ceramics, carbon fibers, polymers, metals and composites enhance osteoblast adhesion and calcium/phosphate mineral deposition. Studies have suggested that nanophase ZnO and TiO(2) may reduce S.epidermidis adhesion and increase osteoblast functions necessary to promote the efficacy of orthopedic implants. [27].

6. Conclusion

It is clear that, recent developments in nanomaterials & nanotechnology will improve dentistry, health care and human life more profoundly than other developments. Great changes come out with great challenges and overcoming these challenges such as ethics regulation, human safety, cost effectiveness etc. also have to be considered. A successful future for nanotechnology will only be achieved through open sharing of ideas and research finding, through testing and frank discussion.

References

[1] “Nanotechnology” - From Wikipedia, the free encyclopedia http://en.wikipedia.org/wiki/Nanotechnology.

[2] Silva GA. Introduction to Nanotechnology and Its Applications to Medicine. *Surg Neurol* 61:216-20,2004.

[3] “Nanomaterial”s - From Wikipedia, the free encyclopedia en.wikipedia.org/wiki/Nanomaterials.

[4] Freitas RA Jr. Nanodentistry. *J Am Dent Assoc* 131 (11): 1559-1566, 2000.

[5] Kong LX, Peng Z, Li SD, Bartold PM. Nanotechnology and its role in the management of periodontal diseases. *Periodontol 2000*, 40: 184-196, 2006.

[6] Mallanagouda Patil, Dhoom Singh Mehta. Future impact of nanotechnology on medicine and dentistry. *J Ind Soc Periodontol* 12(2): 34-40,2008.

[7] Saravana Kumar R, Vijayalakshmi R. Nanotechnology in Dentistry. *Ind J Dent Res.* 17 (2) : 62-65, 2006.

[8] Elangovan S, Tsai PC, Jain S, Kwak SY, Margolis H, Amiji M. Calcium Phosphate Based Nano Vectors for Gene Delivery in Fibroblasts. *J Periodontol Res.* 84 (1): 117-125, 2013.

[9] Shi F, Qi B, Wu L, Wolinsky DT. Wong. The Oral Fluid MEMS/NEMS Chip (OFMNC): Diagnostic & Translational Applications. *Adv Dent Res.* 18(1): 3-5, 2005.

[10] Gau V, Wong D. Oral fluid nanosensor test (OFNASET) with advanced electrochemical-based molecular analysis platform. *Ann NY Acad Sci.* 1098:401-10, 2007.

[11] Song JM, Kasili PM, Griffin GD, Vo-Dinh T. Detection of cytochrome C in a single cell using an optical nanobiosensor. *Anal Chem.* 76(9): 2591-2594, 2004.

[12] Herr AE, Anson V. Integrated Microfluidic Platform for Oral Diagnostics. *Ann N Y Acad Sci.* 1098:362-74, 2007.

[13] Christodoulides N, Floriano PN, Miller CS, Ebersole JL, Mohanty S, Dharshan P et al. Lab-on-a-chip methods for point-of-care measurements of salivary biomarkers of periodontitis. *Ann NY Acad Sci.* 1098:411-428, 2007.

[14] Kim JS, Cho BH, Lee IB, Um CM. Effect of the hydrophilic nanofiller loading on the mechanical properties and the microtensile bond strength of an ethanol-based one-bottle dentin adhesive. *J Biomed Mater Resn B Appl Biomater.* 72(2):284-91, 2005.

[15] Schirrmeister JF, Huber K Two-year evaluation of a new nano-ceramic restorative material. *Clin Oral Investigations.* 10(3):181-6, 2006.

[16] Jhaveri HM, Balaji Nanotechnology: The future of dentistry. *J Ind Prosthodont Soc.* 5: 15-17, 2005.

[17] Zheng Z, Yin W, Zara JN, Li W, Kwak J, Mamidi R,et al. The use of BMP-2 coupled – Nanosilver-PLGA composite grafts to induce bone repair in grossly infected segmental defects. *Biomaterials.* 31(35): 9293-9300, 2010.

[18] Kanaparthy R, Kanaparthy A. The changing face of dentistry: nanotechnology. *Int J Nanomedicine.* 6: 2799-2804, 2011.

[19] Tavakoli M, Bateni E, Rismanchian M, Fath M, Doostmohammadi A, Rabiei A, et al. Genotoxicity effects of nano bioactive glass and Novabone bioglass on gingival fibroblasts using single cell gel electrophoresis (comet assay): An *in vitro* study. *Dent Res J (Isfahan).* 9(3): 314-320, 2012.

[20] Bartold PM, McCulloch CAG, Narayanan AS. Tissue engineering: A new paradigm for periodontal regeneration based on molecular and cell biology. *Periodontology 2000.* 24: 253-269, 2000.

[21] Kohli P, Martin CR. Smart nanotubes for biomedical and biotechnological applications. *Drug News Proespect*. 16(9):566-73, 2003.

[22] Piñón-Segundo E, Ganem-Quintanar. A Preparation and characterization of triclosan nanoparticles for periodontal treatment. *Int J Pharm.* 294 (1-2) :217-32, 2005.

[23] Botelho MA, Martins JG, Reula RS, Queiroz DB, Reula WS. Nanotechnology in ligature-induced periodontitis: protective effect of a doxycycline gel with Nanoparticules. *J Appl Oral Sci*. 18: 335, 2010.

[24] Nagahara A, Mitani A, Fukuda M, Yamamoto H, Tahara K, Morita I. Antimicrobial photodynamic therapy using a diode laser with a potential new photosensitizer, indocyanine green-loaded nanospheres, may be effective for the clearance of Porphyromonas gingivalis. *J Periodontal Res*. 48: 591-599, 2013.

[25] Catledge SA. Nanostructured Ceramics for Biomedical Implants. *J nanoscience and nanotechnology.* 2 (3-4): 293-312, 2002.

[26] Colon G, Ward BC, Webster TJ Increased osteoblast and decreased Staphylococcus epidermidis functions on nanophase ZnO and TiO2. *J Biomedical Mater Res.*.78(3):595-604, 2006.

[27] Meyer U, Bühner M. Fast element mapping of titanium wear around implants of different surface structures. *Clini Oral Implant Res*. 17(2):206-11, 2006.