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Research Paper

Dentistry

Nanotechnology and Periodontics: An Insight

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ABSTRACT

The shift in therapeutic concepts from resection to regeneration has significantly impacted the practice of periodontology. Although the achievement of the goal of complete regeneration of the periodontal tissues could not be possible for many years. Recent developments in nanomaterials and nanotechnology have provided a promising insight into the commercial applications of nanomaterials in the management of periodontal diseases. Various metallic and polymeric materials structured in nano scales and nanomaterials are developed to form an ideal scaffold interfaces with the tissues which provides a new horizon in the periodontal therapy. Nanomaterials can be used in the treatment of dentinal hypersensitivity, in dentifrices, nanofibers can be used as an adjunct to conventional fibers for local drug delivery and tissue engineering scaffolds, and nano textured implant surface. Thus the recent developments in nanomaterials, and nanotechnology have provided a promising insight into the commercial applications of nanomaterials in the management of periodontal diseases.

KEYWORDS : nanotechnology, periodontics, regeneration

Introduction

Scientists in the field of regenerative medicine and tissue engineering are continually looking for new ways to apply the principles of cell transplantation, materials science, and bioengineering to construct biological substitutes that will restore and maintain normal function in diseased and injured tissues(Atala, 2005). In addition, the development of more refined means of delivering medications at therapeutic levels to specific sites is an important clinical issue.

Applications of such technology in dentistry, and periodontics in particular, are no exception as periodontal destruction can be found to increase in prevalence with increasing age(Levy, 1986; Page, 1984). The traditional clinical procedures of scaling, root planning and periodontal flap surgery, if followed by an adequate postoperative supportive periodontal care, results, in most cases, in successful management of progressive periodontal diseases(Hirshfield & Wasserman, 1978; Ramfjord et al., 1987 ; Sanz & Giovannoli, 2000)

More recently, the regenerative treatment of periodontal defects with an agent, or procedure, has attracted enormous interest from materials scientists and also from both private companies and government organizations because of its considerable economic potential(Bartold et al., 2000; Lysaght, Nguy, & Sullivan, 1998) and scientific significance.

One of the emerging areas is tissue engineering that seeks to develop techniques and materials to aid in the formation of new tissues to replace damaged tissues(Bartold et al., 2000).Guided tissue engineering has been successfully used in the treatment intrabony defects(Cortellini & Tonetti, 2000) and furcation defects(McClain & Schallhorn, 2000; Sanz & Giovannoli, 2000). A more general review of tissue engineering concepts in terms of periodontal regeneration has been carried out by Bartold et al (Bartold et al., 2000).

There has been significant progress made in recent years with the development and introduction of various metallic and polymeric materials structured in nanoscales(Doherty et al., 2003; Merkel et al., 2002; Stupp & Braun, 1997; Zhang, 2003) and the development of many biomaterials that form ideal interfaces with tissues(Bitar, Salih, Mudera, Knowles, & Lewis, 2004; Zhang, 2003). Using natural processes as a guide, substantial advances have been made at the interface of nano materials and biology, including the fabrication of Nano fiber materials for three-dimensional cell culture and tissue engineering(Zhang, 2003). One example of such applications in the management of periodontal diseases is the evaluation of two typical cellular components of a hard / soft tissue interface such as the periodontal ligament / mandible and patellar tendon / tibia(Bitar et al., 2004). Tissue engineering of such complex interfaces requires a contiguous scaffold system with at least two cell types associated with the engineering of both hard and soft connective tissues.

Nanotechnology is a technology on a "nano" scale (billionths of a meter). The vision of nanotechnology was introduced in 1959 by Nobel Physicist Feynman (Feynman, 1960)while the term was first used by Norio Taniguchi. Furthermore, Drexler published a book named "Engines of Creation" to promote the prospective of molecular nanotechnology(Drexler, 1986).

Nano came from a Greek word which means "dwarf." A widely used definition for nanotechnology is "The creation and utilization of materials, devices, and systems through the control of matter on the nanometer scale (1-100 nm), i.e. at the level of atoms, molecules, and supra molecular structures(Jain, 2008)."

Technology exploits specific phenomena and direct manipulation of materials on the nano scale. However, nanotechnology is much more than the study of small things; it is the exploration and advancement of materials, devices, and systems showing physical, chemical, and biological properties that are divergent from those found on a larger scale(Kong, Peng, Li, & Bartold, 2006).

Nanotechnology, which utilizes nano volumes and/or nano flows or less in separation sciences, is not limited to the production of micro machined devices, but also being used in bio/clinical research areas of single cell analysis, DNA, RNA, and protein/peptide analysis, in hyphenated technology such as capillary liquid chromatography–electrospray ionization mass spectrometry, sampling techniques, drug delivery, imaging, early detection of tumors, and cancer research(Portney & Ozkan, 2006) and so on. However, the translation process of nanotechnology from a fundamental research tool into clinical practice has to overcome many hurdles. To guarantee sustainable development, there is an urgent need to understand the impact that novel nano-materials could have on human health, and also to develop reliable methods for risk assessments(Maynard et al., 2006 ; Singh & Nalwa, 2007).

Nanotechnology when incorporated into biology is referred as "nanobiotechnology" or "nanomedicine." Similar to Drexler's concept of developing machines from the inside out, the aim of nanobiotechnology is to develop artificial devices (and organs) that could interact with and analyze the cell's contents(Drexler, 1986).

Because of the growing importance of applications of nanotechnology in dentistry, a new field called nanodentistry is evolving. New treatment prospects in dentistry include application of local anesthesia, hypersensitivity cure, complete orthodontic realignment in a single office visit, and continuous oral health care with the help of mechanical dentifrobots that end caries causing bacteria and even renovates blemishes on the teeth where decay has occurred(Rybachuk, Chekman, & Nebesna, 2009).Hence the aim of this paper is to highlight uses of nanotechnology in health care with emphasis on dentistry and periodontics.

Application of nanotechnology in medicine
Nanomedicine
The field of Nanomedicine is the science and technology of diagnosing, treating, and preventing disease and traumatic injury, of relieving pain, and of preserving and improving human health, using nano scale structured materials, biotechnology, and genetic engineering, and eventually complex machine systems and nanorobots(Patil, Mehta, & Guvva, 2008). It was perceived as embracing five main sub disciplines that in many ways are overlapping by common technical issues.

Nanodiagnosis
It helps in diagnosis with the help of nanodiagnostic devices which are used for early disease identification at the cellular and molecular levels. It is used in Stem cell labels and tracers, Stem cell research benefits greatly from nanotechnology by providing answers to stem cell tracking(Shiva-Manjunath & Rana, 2015).

Nanoroboticmicrobivores:which are the artificial phagocytes that patrol the bloodstream and digest the unwanted pathogens including bacteria, viruses or fungi(Freitas-Raj, 2005; Freitas, 2005).

Surgical nanorobotics: A surgical nanorobotics, programmed and directed by a human, could act as a semiautonomous onsite surgeon inside the human body when introduced through the vascular system. Such a device could perform various functions such as searching and diagnosing the pathology and finally treating the lesions by nano manipulation.

It can also be used as Nanogenerators and also as regenerative medicine (Shiva-Manjunath & Rana, 2015).

Nanodentistry
Nanodentistry will make possible the maintenance of comprehensive oral health by employing nanomaterials, biotechnology, including tissue engineering, and ultimately, dental nanorobotics. New potential treatment opportunities in dentistry may include, local anesthesia, dentition renaturalization, and permanent hypersensitivity cure, complete orthodontic realignments in single office visit, covalently bonded diamondized enamel, and continuous oral health maintenance using mechanical dentifrobots.

When the first micro-size dental nanorobots can be constructed, dental nanorobots might use specific motility mechanisms to crawl or swim through human tissue with navigational precision, acquire energy, sense, and manipulate their surroundings, achieve safe cyto penetration and use any of the multitude techniques to monitor, interrupt, or alter nerve impulse traffic in individual nerve cells in real time. These nanorobot functions may be controlled by an onboard nanocomputer that executes preprogrammed instructions in response to local sensor stimuli. Alternatively, the dentist may issue strategic instructions by transmitting orders directly to in-vivo nanorobots via acoustic signals or other means(Patil et al., 2008).

Applications in Clinical Dentistry
Nano technology has wide usage in clinical dentistry such as; oral cancer diagnosis and treatment, nanoneedles and nanoanesthesia, nanosolutions, use in orthodontics, nanocomposites, nanoencapsulation, tooth repair/nanotissueengineering (biomimicry) and nanofibers(Shiva-Manjunath & Rana, 2015).

Application in periodontics
The application of nanotechnology in the periodontal management was put forward by Kong et al(Kong et al., 2006). The idea given by their researches formulated many concepts regarding tissue engineering in periodontal regeneration.

Treatment of dentinal hypersensitivity
Changes in pressure transmitted to the pulp hydrodynamically are the main cause of dentinal hypersensitivity. The dentinal tubules of a hypertensive tooth have twice the diameter and eight times the surface density of those in non-sensitive teeth. Nanorobots selectively and accurately block these dentinal tubules using native materials, thus offering quick and permanent relief to the patient(Archana, Jasjit, Shuchita, Aarti, & Priyanka, 2011).

Nanorobotic dentifrices (dentifrobots)
Nanorobotic dentifrices in the form of mouthwash or toothpaste, cover all subgingival, and metabolize trapped organic matter into harmless and odorless vapors. These nanorobot dentifrices called dentifrobot scan identify and destroy pathogenic bacteria that exist in the plaque and oral cavity. Invisibly small dentifrobots (1-10 μ), crawling at 1-10 μ/s, have the advantages of being inexpensive and safe as they are purely mechanical devices that would safely deactivate themselves if swallowed(Shiva-Manjunath& Rana, 2015).

Periodontal drug delivery
The science of periodontics has witnessed considerable development with the advent of nanopharmaceuticals, nanosensors, nanoswitches, and nano delivery systems. Triclosan-loaded nanoparticles development emerged as a new delivery system for the treatment of periodontal disease. Preliminary in vivo study had been performed in dogs, which concluded that triclosan nanoparticles were able to reduce the inflammation.

Drugs can be incorporated into nanospheres composed of a biodegradable polymer. This enables timely release of the drug as the nanospheres degrade and specific site drug delivery. For example, restinin in which tetracycline is incorporated into microspheres for drug delivery by local means to a periodontal pocket(Shiva-Manjunath & Rana, 2015).

Genomics and proteomics research is already rapidly elucidating the molecular basis of many diseases. This has brought new opportunities to develop powerful diagnostic tools able to identify genetic predisposition to diseases. In the future, point of care diagnosis will be routinely used to identify those patients requiring preventive medication to select the most appropriate medication for individual patients, and to monitor response to treatment. Nanotechnology has a vital role to play in realizing cost-effective diagnostic tools(Patil et al., 2008).

Nanotechnology in tissue engineering
The necessary strategies for complete regeneration of human tissues should be the ultimate endpoint for the field of regenerative medicine and engineering. There has been significant progress made in recent years with the development and introduction of various metallic and polymeric materials structured at the nanoscales (Bitar et al., 2004; Doherty et al., 2003; Zhang, 2003). From the definition provided by the National Nanotechnology Initiative, nanotechnology exploits specific phenomena and direct manipulation of materials on the nanoscale. However, nanotechnology is much more than the study of small things; it is the research and development of materials, devices, and systems exhibiting physical, chemical, and biological properties that are different from those found on a larger scale. Thus nanotechnology can be best understood as a broad collection of technologies – from diverse fields such as physics, materials science, engineering, chemistry, biochemistry, medicine, and optics – each of which may have different characteristics and applications(Shiva-Manjunath & Rana, 2015).

Bone regeneration
Bone transplants are commonly performed (2.2 million bone grafts performed annually worldwide). These transplants need scaffolds that are porous 3D structures which provide cell support and guide bone formation. Despite numerous investigations to develop such porous materials, it is still challenging to fully harness bone's capability to regenerate itself. Bone regeneration requires three essential elements: Osteoconductive matrix (scaffold), oosteoinductive signals, osteogenic cells that can respond to these signals, and an adequate blood supply(Saiz, Zimmermann, Lee, Wegst, & Tomsia, 2013).

The first step, fabrication of strong and porous scaffolds, holds prime importance in the whole process. Nanotechnology delivers new useful tools to engineer the scaffold's internal surfaces and to create devices used in drug delivery with carefully controlled spatial release patterns. Different techniques have been suggested to successfully seed scaffolds along with cells. They can be roughly divided into two main groups, i.e. either attaching the cells to the internal scaffold surface or distributing them in the scaffold porosity with the help of a gel-like vehicle. Injectable gels comprising of cells could also be used directly in non-load bearing presentations. It has been detected that the presence of calcium within the matrix favors the osteogenic differentiation of the appropriate progenitor cell(Saiz et al., 2013).

Bone replacement materials

Bone is said to be a natural nanostructure which is composed of organic compounds mainly of collagen. Nanotechnology targets to imitate this natural structure for development of nanobone, which can be used in dental applications. Nanocrystal appears as a loose microstructure with nanopores which are situated between these crystals. Bone display properties that are consistently far more superior to their individual constituent phases. The macro-scale orientation of the bones is either compact/cortical (dense material found at the surface of bones) or spongy/cancellous (foam-like material). Compact bone is composed of osteons which surrounds and shields the blood vessels. Osteons have a lamellar pattern, with each individual lamella having fibers arranged in geometrical patterns. Several collagen fibrils collectively form the fibers. These mineralized collagen fibrils are the basic building blocks of bone, composed of collagen protein called tropocollagen. The surfaces of the pores are modified by adding silicon molecules, which then helps in adsorption of the protein. These hydroxyapatite nanoparticles can be used for treating bone defects in periodontal diseases(Saravana & Vijayalakshmi, 2006).

Scaffolds and nanotechnology

Scaffolds play a pivotal role in tissue engineering. Scaffolds may be populated by cells before implantation or, if they are information rich or permissive constructs, they may mobilize host cells, or cells may simply migrate into them, after implantation. Scaffolds are known as artificial extracellular matrix and help in accommodating the cells and guide them to grow, proliferate, migrate, and differentiate, leading to the formation of a specific tissue while secreting the extracellular matrix that is required for tissue regeneration. Several in vitro and in vivo experiments have shown that nanostructured materials, which mimic the nanometer topography of the native tissues, improve biocompatible responses, and result in better tissue integration(Kriparamanan, Aswath, Zhou, Tang, & Nguyen, 2006). Nanostructured materials have unique surface properties (such as energy, wettability, topography, etc.) that make them intriguing for applications involving interactions with proteins and subsequently cells(Srisuwan et al., 2006).

Nanotechnology and implants

Besides surface contact area and surface topography, bone bonding, and stability play a major role in implant success and osseointegration. Bone growth and implant success can be accelerated by the use of nanotechnology.

Osteoblast formation on a more complex implant surface is formed by the addition of nanoscale deposits of hydroxyapatite and calcium phosphate particles(Albrektsson, Sennerby, & Wennerberg, 2008; Goené, Testori, & Trisi, 2007). Material engineering, and hence implant dentistry, has advanced extensively on the basis of researches conducted on the effects and subsequent optimization of micro topography and surface chemistry. These new implants constructed on the basis of this technology are more acceptable as they enhance the integration of nano coatings resembling biological materials to the periodontal tissues(Saiz et al., 2013). In addition, implant surfaces coated with titanium oxide nanotubes and laced with silver nanoparticles serve the purpose of fighting infection thus increases the shelf life of the implants(Shiva-Manjunath & Rana, 2015).

Peri-implantitis affected parts become covered by an infected smear layer of instrumentation debris after routine implant preparation, which seems to compromise fibrin clot adhesion to such altered surfaces. In addition, continuous flap mobility and early clot retraction could draw the clot-blended graft complex away from the implant surface with subsequent creation of a micro-gap graft, epithelialization, and eventual implant surface recontamination. For that reason, treating a peri-implantitis affected implant surface should include complete removal of the infected biofilm and the smear like layer, resulting in complete exposure of the roughened titanium implant surface. This should be followed by maximizing clot-blended graft adhesion to the implant surface through application of a graft material with a particle size smaller than that of the implant surface pores. Such mechanical integration is thought to reduce the possibility of the implant bone microgap, a factor that could ensure complete protection of the underlying defect-filled regenerative materials or blood clot. This, along with subsequent enhanced bone regeneration, could be interpreted as a true reosseointegration.

Particle size seemed to be an important factor that optimizes adhesion of particles to the exposed implant surface. Such improved adhesion is likely to retard the apical migration of the epithelial attachment, a factor that could enhance reosseointegration. Further periimplantitis affected surface conditioning with citric acid improves nano particle sized hydroxyapatite blended clot adhesion to titanium implant surfaces(Gamal, Abdel-Ghaffar, & Iacono, 2013).

Growth factors such as platelet-derived growth factor (PDGF) have significantly enhanced periodontal therapy outcomes with a high degree of variability, mostly due to the lack of continual supply for a required period of time. One method to overcome this barrier is gene therapy. PDGF-B gene delivery in fibroblasts using nano-sized calcium phosphate particles (NCaPP) as vectors has found to significantly enhance fibroblast proliferation(Elangovan, Jain, Tsai, Margolis, & Amiji, 2013).

Conclusion

Nanotechnology has tremendous potential, but social issues of public acceptance, ethics, regulation, and human safety must be addressed before molecular nanotechnology can be seen as the possibility of providing high quality dental care to the 80% of the world's population that currently receives no significant dental care.

Although the achievement of the goal of complete regeneration of the periodontal tissues (cementum, periodontal ligament, and bone) for periodontal management was not possible for many years, recent developments in nanomaterials and nanotechnology have provided a promising insight into the commercial applications of nanomaterials in the management of periodontal diseases.

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