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Nanotechnology and dentistry

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ABSTRACT

Nanotechnology deals with the physical, chemical, and biological properties of structures and their components at nanoscale dimensions. Nanotechnology is based on the concept of creating functional structures by controlling atoms and molecules on a one-by-one basis. The use of this technology will allow many developments in the health sciences as well as in materials science, biotechnology, electronic and computer technology, aviation, and space exploration. With developments in materials science and biotechnology, nanotechnology is especially anticipated to provide advances in dentistry and innovations in oral health-related diagnostic and therapeutic methods. (Eur J Dent 2013;7:145-151)

Key words: Nanotechnology; dentistry; nanodentistry; nanocomposite

INTRODUCTION

Science is presently undergoing a great evolution, taking humanity to a new era: the era of nanotechnology.[1] The opportunity to witness the beginning of a pioneering development in technology is encountered rarely.

The application of nanotechnology to dentistry and the time that will be required to implement the results of research into practice are the first questions that arise regarding nanotechnology in dentistry.[2]

The word "nano," which is derived from the Greek word (nannos) meaning "dwarf," is a prefix that literally refers to 1 billionth of a physical size.[1] One nanometer (nm) is a unit of length that equals 1 billionth of a meter.[3] Given that a single hair strand has a thickness of 100,000 nm, it becomes easier to visualize what is meant by "nano" and to understand its significance.[4] The size of atoms is approximately 0.1 nm. Considering that the size of a usable nanostructure is 1 to 100 nm, it is clearly seen that the area of nanotechnology works at the level of atoms and molecules.[3]

According to the definition of the National Nanotechnology Initiative, nanotechnology is the direct manipulation of materials at the nanoscale.[5] This term defines a technology that enables almost complete control of the structure of matter at nanoscale dimensions. Nanotechnology will give us the ability to arrange atoms as we desire and subsequently to achieve effective, complete control of the structure of matter.[6,7]

The aims of nanotechnology are to enable the analysis of structures at the nanoscale, to understand the physical properties of structures at the nanoscale dimension, to manufacture nanoscale structures, to develop devices with nano-precision, and to establish a link between nanoscopic

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and macroscopic universes by inventing adequate methods.[8]

Nanotechnology is based on the idea of creating functional structures by controlling atoms and molecules on a one-by-one basis.[1] What makes nano-particles interesting and bestows unique features upon them is the fact that their size is smaller than the critical lengths defining many physical events.[9] In general, nanotechnology is translated as "the science of the small."[10] However, in addition to creating small structures, nanotechnology involves inventing materials, devices, and systems with physical, chemical, and biologic properties that differ from those of large-scale structures.[5]

DEVELOPMENTAL PROCESS OF NANOTECHNOLOGY

Nano-phase materials were first discussed academically in 1959 at the annual meeting of the American Physical Society. At this meeting, Nobel Prize winning physicist Richard P. Feynman (1918-1988) gave a speech titled "There is plenty of room at the bottom." In this speech, Feynman said that manufacturing at the dimension of atoms and molecules would result in many new inventions; in addition, he stated that particular methods for measurement and manufacturing at the nanoscale should first be developed to realize such a possibility.[9] Feynman's famous speech is accepted as the beginning of nanoscience and nanotechnology.[11] Since then, both experimental and theoretical developments have been proceeding rapidly.

NANOMEDICINE

Advances in the medical implementations of nanotechnology have resulted in the formation of a new field called nanomedicine.[11] This concept was first put forward in 1993 by Robert A. Freitas Jr. and was defined as observing, controlling, and treating the biological systems of the human body at the molecular level using nano-structures and nano-devices.[12]

Nanomedicine includes various applications ranging from drug release with nanospheres to tissue scaffolds based on nanotechnologic design that realize tissue formation, and even nanorobots for diagnostic and therapeutic purposes.[13] Drug molecules transported through the body by the circulatory system may cause undesirable adverse effects in untargeted regions. On the other hand, nanorobots can recognize unhealthy cells and can find and destroy them wherever they are located. Drug delivery to the exact target is of particular importance in cancer in order to destroy all of the cancer cells and at the same time avoid harming healthy cells.[14]

Nanomedicine can overcome many important medical problems with basic nanodevices and nanomaterials, some of which can be manufactured today. The results of many studies performed today in the field of nanomedicine are very close to transformation into practice; therefore, it can be said that these successful developments are inevitable. Nanomedicine provides improvements in available techniques in addition to developing fully new techniques.[13,15]

NANOTECHNOLOGY IN DENTISTRY

Similar to nanomedicine, the development of nanodentistry will allow nearly perfect oral health by the use of nanomaterials and biotechnologies, including tissue engineering and nanorobots.[11]

Tissue engineering and dentistry

Potential applications of tissue engineering and stem cell research in dentistry include the treatment of orofacial fractures, bone augmentation, cartilage regeneration of the temporomandibular joint, pulp repair, periodontal ligament regeneration, and implant osseointegration. Tissue engineering enables the placement of implants that eliminate a prolonged recovery period, are biologically and physiologically more stable than previously used implants, and can safely support early loading.[16,17]

Studies related to the regeneration of bone tissue constitute a major part of the studies in the tissue-engineering field. Nanoscale fibers are similar in shape to the arrangement between collagen fibrils and hydroxyapatite crystals in bone. The biodegradable polymers or ceramic materials that are often preferred in bone tissue engineering may not have sufficient mechanical endurance despite their osteoconductive and biocompatible properties despite their osteoconductive and biocompatible properties. Studies performed in recent years indicate that nanoparticles can be used to enhance the mechanical properties of these materials. The main reason for preferring nanoparticles is that the range of dimension of these structures is the same as that of cellular and molecular components.[4,18] Bone replacement materials developed via nanotechnology are commercially available.[1,19, 20]

Bone grafts with better characteristics can be developed with the use of nanocrystalline hydroxyapatite. Furthermore, it was shown that nanocrystalline hydroxyapatite stimulated the cell proliferation required for periodontal tissue regeneration.[21]

Bio-nano surface technology and dental implants

The natural bone surface has a roughness of approximately 100 nm, and such nano details are therefore important on the surfaces of implants. Osteoblast proliferation has been induced through the creation of nano-size particles on the implant surface.[4,22] Roughing the implant surface at the nanoscale level is important for the cellular response that occurs in the tissue.[23,24]

Titanium implants treated with a nanostructured calcium surface coat were inserted into rabbit tibias, and their effect on osteogenesis was investigated; the nanostructured calcium coat increased the responsiveness of the bone around the implant.[25] Many in-vitro studies have shown that the nanotopography of the implant surface considerably affects osteogenic cells and that the nanoscale surface morphology enhances osteoblast adhesion. Moreover, the nanoscale surface morphology augments the surface area and thus provides an increased implant surface area that can react to the biologic environment.[25-28]

Dental nanorobots

Although medical robots are not anticipated to have an effect on dentistry in the near future, it is not too early to consider their potential effects.[2] Dental nanorobots are able to move through teeth and surrounding tissues by using specific movement mechanisms. Nanocomputers that have been previously programmed via acoustic signals used for ultrasonography can control nanorobotic functions.[11]

Nanorobots (dentifrobots) left by mouthwash or toothpaste on the occlusal surfaces of teeth can clean organic residues by moving throughout the supragingival and subgingival surfaces, continuously preventing the accumulation of calculus. These nanorobots, which can move as fast as 1 to 10 micron/second, are safely deactivated when they are swallowed.[1]

Nanocomposites

The increasing interest in esthetic restorations in recent years has led to further development of materials that have the same color as that of teeth.[29] The latest advance in composite resins is the implementation of nanoparticle technology into restorative materials.[16,30] Nanotechnology has enabled the production of nano-dimensional filler particles,[31] which are added either singly or as nanoclusters into composite resins. Nanofillers are different from traditional fillers.[32,33] When the filler for traditional composites is produced, large particles are minified by pinning; however, these methods cannot reduce the size of a filler that is smaller than 100 nm.[31, 33] Nanotechnology allows the production of nano-sized filler particles that are compatible with dental composites; therefore, a greater amount of filler can be added into the composite resin matrix.[31]

Nanoparticles allow the production of composites with a smooth surface after the polishing process and confer superior esthetic features to the material. Composite resins containing such particles are easy to shape and have a high degree of strength and resistance to abrasion. Therefore, the area of use of resins containing nanoparticles is wider than that of composites containing hybrid and microfill fillers.[29, 34]

In contrast to hybrid composites in which large particles can be separated from the matrix, only poorly attached nanoclusters are separated during abrasion in nanocomposites; thus, a well-polished restoration surface can retain its smoothness for a long time.[29] The particles that are separated from the surface of the nanocomposites and form defects on the surface during abrasion are nano in size, which is smaller than the wavelength of light.[33] Since particles in the wavelength of visible light (0.4 to 0.8 μm) do not reflect light, the material has superior optic character.[29] The fillers in nanocomposites have higher translucence since they are smaller than the wavelength of light, allowing the generation of more esthetic restorations with a vast range of color options.[33]

Bacteria cause plaque accumulation and subsequent periodontal disease by adhering to the rough surfaces of restorations.[35] Several reports have indicated that significantly smoother surfaces were achieved using composites with nanofiller compared to other composites; This is because nanocomposites have much smaller sizes and contain much higher amounts of filler.[31,35]

Nanofiller technology has enabled the production of nanofill composites by bringing together the esthetic features of microfill composites and the mechanical features of hybrid composites.[29,33,36] In-vitro studies have shown that these composites had advantageous physical, mechanical, and esthetic features. Considering these features, the nanocomposite may be a concrete example of an ideal composite.[31,33,35,37-39] However, before nanofill and nanohybrid composites take their anticipated places in routine practice, their successful in-vitro performance should be confirmed by clinical studies.[10,29,32,40] Although existing clinical studies have demonstrated that use of nanocomposites is successful after 1- and 2-year follow-up, this should be confirmed by long-term clinical studies.

Nanocomposite artificial teeth

Artificial teeth made of nanocomposite have also been produced. In these artificial teeth, inorganic fillers in nano-dimensions are diffused homogenously without any accumulation in the matrix. Therefore, the smoothness of the surface can be preserved even when the teeth are eroded. Tests have shown that nanocomposite artificial teeth are more durable than acrylic teeth and microfill composite teeth and have a higher resistance to abrasion.[41-44] Moreover, composite resin artificial teeth containing nanofiller show superior color.[45]

Dental tissues and nanostructures

Although enamel, cement, and bone are formed by the organized accumulation of apatite crystals with carbon dioxide, enamel tissue has distinct characteristics because it does not contain collagen and remodeling is not possible. During enamel biomineralization, spontaneous self-assembly of the amelogenin protein in nano-spheres plays an important role in controlling the growth of apatite crystals with carbon dioxide. This process can be implemented for forming other mineralized tissues such as bone and cement, in which nanostructures were similarly used.[5]

Nanomaterials for periodontal drug delivery

Researchers have attempted to generate an effective and satisfactory drug delivery system for the treatment of periodontal diseases by producing nanoparticles impregnated with triclosan. It was concluded that the application of triclosan particles into the test area alleviated inflammation.[5] Although this study investigated only periodontal therapy, it indicated that targeted drug delivery with nanomaterials is possible for other treatments. The best example of the future use of this technology is a procedure called Arestin®, in which microspheres containing tetracycline are placed into periodontal pockets and tetracycline is administered locally.[5]

An in-vitro study performed with a toothpaste containing nanosized carbonate apatite showed that dentin tubules were effectively sealed, which is important for sustained treatment of dentin sensitivity.[46]

Nanotechnology for preventing dental caries

The use of a toothpaste containing nanosized calcium carbonate enabled remineralization of early enamel lesions.[47] Furthermore, a study that investigated the bacteriostatic effects of silver, zinc oxide, and gold nanoparticles on Streptococcus mutans, which causes dental caries, reported that compared to the other nanoparticles, silver nanoparticles had an antimicrobial effect in lower concentrations and with lower toxicity.[48]

Digital dental imaging

Advances in digital dental imaging techniques are also expected with nanotechnology. In digital radiographies obtained by nanophosphor scintillators, the radiation dose is diminished and high-quality images are obtained.[49]

Applications of nanotechnology in oral and maxillofacial surgery

Selective cell manipulation and surgery performed with tools sized at the molecular level will provide great benefits, particularly in tumor tissue surgery.[50]

FUTURE FIELDS OF APPLICATION OF NANOTECHNOLOGY IN DENTISTRY

In nanodentistry, millions of active analgesic nanoparticles in a colloidal suspension are placed into the patient's gingiva, and the anesthesia effectiveness is controlled by the dentist via nanorobots moving into the gingival sulcus. Nanorobotic analgesics are an excellent modality to provide comfort to the patient and alleviate anxiety. Many of the adverse effects and complications associated with the use of typical local analgesic solutions are absent.

Nanodental techniques for major dental repair have been advanced by technologic developments such as genetic engineering, tissue engineering, and tissue regeneration. At some time in the future, it will be possible to form a new tooth in-vitro. Preparing an autologous tooth that has both mineral and cellular dental components will be made possible by advances in research, and this process will eventually be achievable in the dentist's office.

Nanotechnology will offer perfect therapeutic methods for esthetic dentistry. All teeth that undergo treatment such as fillings or crowns will be restored with natural biologic materials in a manner that is indistinguishable from natural dentition.

Dentin sensitivity is another pathology that is suitable for nanodental treatment. Many therapeutic agents provide only a temporary effect for this common, painful condition. However, dental nanorobots can seal specific tubules by using natural biomaterials within a few minutes and provide a quick and permanent recovery from this condition.

Orthodontic nanorobots can directly manipulate all of the periodontal tissues, including gingival, periodontal ligament, cement, and alveolar bone. They can correct, rotate, or vertically reposition the teeth within a few hours in a pain-free manner.

The durability and appearance of teeth can be improved by inserting artificial materials such as sapphire or diamond into the outer layers of the enamel with covalent bonds. Although pure sapphires and diamonds are fragile, their ultimate strength can be augmented by the addition of materials such as carbon nanotubes. Sapphire can be produced in almost all colors from the color scale. This feature provides a cosmetic alternative to standard whitening techniques.

The once-a-day application of a mouthwash or toothpaste that delivers nanorobotic structures will result in the metabolism of organic compounds into harmless and odorless structures and the continuous cleaning of calculus. These dentifrobots, which are nearly invisible (1 to 10 μm), will have the mobility of an amoeba with a velocity of 1-10 μm/second. Their production is inexpensive, and they are fully mechanic devices. Furthermore, their activity can be stopped harmlessly in case they are swallowed. Distinctively manufactured dentifrobots recognize and destroy pathogenic bacteria in plaque and other regions, but they do not affect approximately 500 harmless species in normal flora and thus contribute to the formation of a healthy ecosystem. Dentifrobots constitute a continuous barrier to halitosis by eliminating bacterial putrefaction products, a major cause of oral malodor. Thus, tooth loss and gingival diseases will be eliminated by providing these daily dental practices from a young age.[11]

CONCLUSION

Although the effect of nanotechnology on dentistry is limited to the use of currently available materials, rapidly progressing investigations will ensure that developments that seem unbelievable today are possible in the future. The future utilization of the advantages of nanotechnology will facilitate improvements in oral health. Advanced restorative materials, new diagnostic and therapeutic techniques, and pharmacologic approaches will improve dental care.

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