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REVIEW ARTICLE

Dental Biomaterials

Nanotechnology applications in medicine and dentistry

Jyoti Gupta

Department of Periodontics, Dr H.S.J. Institute of Dental Sciences and Research, Chandigarh, India

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Correspondence
Dr Jyoti Gupta, Department of Periodontics,
Dr H.S.J. Institute of Dental Sciences and
Research, Sector-25, South Campus,
Panjab University, Chandigarh, India.
Tel: +91-98142-53329
Fax: +91-172-2724912
Email: jyoti.guptaa@yahoo.co.in

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Abstract

Nanotechnology, or nanoscience, refers to the research and development of an applied science at the atomic, molecular, or macromolecular levels (i.e. molecular engineering, manufacturing). The prefix “nano” is defined as a unit of measurement in which the characteristic dimension is one billionth of a unit. Although the nanoscale is small in size, its potential is vast. As nanotechnology expands in other fields, clinicians, scientists, and manufacturers are working to discover the uses and advances in biomedical sciences. Applications of nanotechnology in medical and dental fields have only approached the horizon with opportunities and possibilities for the future that can only be limited by our imagination. This paper provides an early glimpse of nanotechnology applications in medicine and dentistry to illustrate their potentially far-reaching impacts on clinical practice. It also narrates the safety issues concerning nanotechnology applications.

Introduction

Nanotechnology is the engineering of molecularly precise structures. The term “nanotechnology” was coined by Professor Kerie E. Drexler, a lecturer and researcher of nanotechnology. The prefix “nano” means 10^{-9} or one billionth of a unit. The nanoscale is approximately 1000 times smaller than a microscale, which is approximately 1/80 000 the diameter of a human hair. These small scientific scales were first revolutionized by Richard Feynman at his famous speech at the Annual Meeting of the American Physical Society in 1959 entitled: “There is plenty of room at the Bottom”. He proposed that machines and tools that make smaller machine tools could in turn be used to make even smaller machines and tools, right down to molecular levels.[1] He suggested that such nanomachines, nanorobots, and nanodevices could ultimately be used to develop a wide range of atomically precise microscopic instrumentation and manufacturing tools. In his historical lecture in 1959, he concluded by saying, “This is a development, which I think cannot be avoided”.[2]

Nanotechnology in medicine has been recently reviewed (2002–present) from various perspectives relative to the human molecule–tissue interface,[3–5] and has led to the emergence of a new field called nanomedicine. This is the science and technology of diagnosing, treating, and preventing disease and traumatic injury in order to relieve pain and preserve and improve human health through the use of nanoscale-structured materials, biotechnology, and genetic engineering, and eventually, complex molecular machine systems and nanorobots.[6] Once one considers other potential applications of nanotechnology to medicine, it is not difficult to imagine the impact on nanodentistry. The development of nanodentistry will make possible the maintenance of near-perfect oral health through the use of nanomaterials[7] and biotechnology,[8–10] including tissue engineering[11,12] and nanorobotics.

Nanotechnology in medicine

The potential applications of nanotechnology in medicine are vast. These include imaging and diagnostics, targeted drug delivery, nano-enabled therapies, and tissue engineering.

Diagnostics

In nanodiagnostics, the ultimate goal is to identify diseases at the earliest stage possible, ideally at the level of a single cell. Nanotechnology-on-a-chip is a dimension of lab-on-a-chip technology. Magnetic nanoparticles bound to a suitable antibody are used to label specific molecules, structures or microorganisms. Gold nanoparticles tagged with short segments of DNA can be used for the detection of genetic sequence in a sample. Multicolor optical coding for biological assays has been achieved by embedding different-sized quantum dots into polymeric microbeads. Quantum dots are semiconductor nanoparticles that have unique optical and electrical properties. When exposed to light, these nanoparticles emit distinctly different colors depending on their size (the smaller the quantum dots, the brighter the color). Although fluorescent dyes have been used for decades in the human body for biomedical imaging (to track the effects of cancer drugs, for instance), they are often imprecise and only visible for short time periods. Fluorescent quantum dots will provide a brighter, more precise, and longer lasting alternative. Quantum dots can be injected into cells or attached to proteins in order to track, label, or identify specific biomolecules, and these offer ultimate detection sensitivity.

Drug delivery

Nanotechnology has had a beneficial impact in medicine in that it delivers drugs to specific cells using nanoparticles. The overall drug consumption and side-effects can be lowered significantly by depositing the active agent in the morbid region only and in no higher dose than needed. This highly selective approach reduces cost and human suffering. Examples include dendrimers and nanoporous materials, as well as blocking co-polymers, which form micelles for drug encapsulation. They could hold small drug molecules, transporting them to the desired location. Small nanoelectromechanical systems are being investigated for the active release of drugs. Some potentially important applications include cancer treatment with iron nanoparticles or gold shells. Targeted or personalized medicine reduces drug consumption and treatment expense, resulting in an overall societal benefit by reducing the cost to the public health system. Nanotechnology is also opening up new opportunities in implantable delivery systems, which are often preferable to the use of injectable drugs, because the latter frequently display first-order kinetics (the blood concentration goes up rapidly, but drops exponentially over time). This rapid rise might cause difficulties with toxicity, and drug efficacy can diminish as the drug concentration falls below the targeted range.

One of the most highly publicized areas of nanomedicine research involves gold nanoshells to detect and treat cancerous tumors. This is an area where detection and therapy might overlap. Nanoshells are particles of silica (glass) that are completely coated with gold, made up of a few million atoms. They can be produced in a range of sizes, with diameters smaller than 100 nm to as large as several hundred nanometers. When injected into the blood stream, they naturally congregate at the tumor sites, and therefore, no additional targeting is necessary. In order to feed their growth, tumors create many blood vessels (neoangiogenesis) very quickly, so the vessels are often defective, allowing the nanoshells to slip through vascular ‘‘leaks’’ and gain access to the tumor. Detecting and targeting tumors by exploiting their surrounding vascular defects is known as enhanced permeability and retention effect. A nanoshell captures light and focuses it around itself. By manipulating the size of the nanoshells, it is possible to change the way they absorb light. The goal in cancer detection and therapy is to ‘‘tune’’ the nanoshells to interact with near-infrared light (NIR). When exposed to NIR, the nanoshells act like a swarm of fireflies’ and light up the area where they have congregated (i.e. tumor sites). Once the nanoshells have completed their imaging tasks, they become therapeutic agents. The area around the nanoshells heats up and the tumor ‘‘cooks’’ until it is ablated. These claims will have to be closely scrutinized, as nanoshells will likely take up permanent residence in the body, and it is not clear how or if the body could excrete them.

Tissue engineering

Nanotechnology can play a pivotal role in the development of cost-effective therapies for *in situ* tissue regeneration. This involves not only a deeper understanding of the basic biology of tissue regeneration, but also identifying effective ways to initiate and control the regenerative process. This ‘‘nanobiomimetic’’ strategy depends on three basic elements:

(**a**) intelligent biomaterials;
(**b**) bioactive signaling molecules;
(**c**) cells.

By ‘‘tailoring’’ resorbable polymers at the molecular level for specific cellular responses, nanotechnology can assist in the development of biomimetic, intelligent biomaterials. These biomaterials are designed to react positively to changes in the immediate environment, stimulating specific regenerative events at the molecular level, directing cell proliferation, cell differentiation, and extracellular matrix production and organization. The sequential signaling of bioactive molecules, which triggers regenerative events at the cellular level, is necessary for the fabrication and repair of tissues. Nano-assisted technologies should enable the sequential delivery of proteins, peptides, and genes to mimic nature’s signaling cascade.

As a result, bioactive materials are produced, which release signaling molecules at controlled rates that in turn activate the cells in contact with the stimuli.

Finally, a major focus of ongoing and future efforts in regenerative medicine will be to effectively exploit the enormous self-repair potential that has been observed in adult stem cells. Nano-assisted technologies will aid in achieving two main objectives: (a) to identify signaling systems, in order to leverage the self-healing potential of endogenous adult stem cells; and (b) to develop efficient targeting systems for stem cell therapies. Of huge impact would also be the ability to implant cell-free, intelligent bioactive materials that would effectively provide signaling to stimulate the self-healing potential of the patient's own stem cells.

Nanorobots in surgery

Surgical nanorobots could be introduced into the body through the vascular system or at the ends of catheters into various vessels and other cavities in the human body.[13] A surgical nanorobot, programmed or guided by a human surgeon, could act as a semiautonomous onsite surgeon inside the human body. Such a device could perform various functions, such as searching for pathology and then diagnosing and correcting lesions by nanomanipulation, coordinated by an onboard computer while maintaining contact with the supervising surgeon via coded ultrasound signals. The earliest forms of cellular nanosurgery are already being explored. For example, a rapidly vibrating (100 Hz) micropipette with a <1 micron tip diameter has been used to completely cut dendrites from single neurons without damaging cell viability. Axotomy of roundworm neurons was performed by femtosecond laser surgery, after which the axons functionally regenerated. A femtolaser acts like a pair of nanoscissors by vaporizing tissue locally, while leaving adjacent tissue unharmed.

Nanorobotics in gene therapy

Medical nanorobots can readily treat genetic diseases by comparing the molecular structures of both DNA and proteins found in the cell to known or desired reference structures.[14] Any irregularities can then be corrected, or desired modifications can be edited in place. In some cases, chromosomal replacement therapy is more efficient than in cytorepair. Floating inside the nucleus of a human cell, an assembler-built repair vessel performs genetic maintenance. Stretching a supercoil of DNA between its lower pair of robot arms, the nanomachine gently pulls the unwound strand through an opening in its prow for analysis. Meanwhile, the upper arms detach regulatory proteins from the chain and place them in an intake port. The molecular structures of both DNA and proteins are compared to information stored in the database of a larger nanocomputer positioned outside the nucleus and connected to the cell-repair ship by a communications link. Irregularities found in either structure are corrected, and the proteins reattached to the DNA chain, which recoils into its original form. With a diameter of only 50 nm, the repair vessel would be smaller than most bacteria and viruses, yet capable of therapies and cures well beyond the reach of present-day physicians.

Overview of nanostructures for dental applications

Nanoparticles

Nanoparticles (molecular units typically defined as having diameters of between 0.1 and 100 nm) of various compositions represent the most widespread use of nanoscale units in dentistry. They are currently being used in resin-based composite restorations (RBC). Considerable research related to nanocomposites is focused on tailoring newer types of silane bonding agents for optimal use with nanoparticles in RBC. Organosilanes,[15] such as allyltriethoxysilane, have demonstrated good compatibility with nanoparticle fillers, such as TiO_2. Nanoparticles and associated modifications of existing RBC systems have a considerable record of demonstrated clinical utility and widespread use.

Nanorods

Nanorods are of particular interest in a restorative context. Chen *et al.* have synthesized enamel prism-like hydroxyapatite (HA) nanorods that exhibit self-assembly properties.[16] Since they are similar to the enamel rods that make up the basic crystalline structure of dental enamel, nanorods could contribute to a practical artificial approximation of such a naturally occurring structure.

Nanospheres

Nanospheres are explored in restorative systems in conjunction with calcium phosphate deposition and amelogenin nanochain assembly to mimic the nanoprocesses already inherent in natural tooth development.

Nanotubes

Nanotubes of various types have been investigated for dental applications. Titanium oxide nanotubes have been shown *in vitro* to accelerate the kinetics of HA formation, mainly in a context of bone-growth applications for dental implant coatings.[17] More recently, modified single-walled carbon nanotubes (SWCNT) have been shown to improve the flexural strength of RBC. These SWCNT had silicon dioxide applied to them in conjunction with specialized organosilane bonding agents.[18]

Nanofibers

Nanofibers and their uses for biomedical applications have been reviewed.[19] Polymer nanofibers, with diameters in the nanometer range, possess a larger surface area per unit mass and permit an easier addition of surface functionalities compared to polymer microfibers. Polymer nanofiber materials have been studied as drug-delivery systems, scaffolds for tissue engineering, and filters. More recently, nanofibers have been used to generate ceramics containing HA and fluor-HA.[20] Nanofibrillar silicate crystals have also been recently studied in the reinforcement of dental composites, specifically a combination of the widely used 2,2′-bis-(4-[methacryloxypropoxy]-phenyl)-propane, with triethylene glycol dimethacrylate added as a thinning agent.[21,22] Added in the correct proportions and with uniform distribution of the fibers/crystals, nanofibers have been demonstrated to improve the physical properties of these composites.

Dendrimers and dendritic copolymers

Dendrimers and dendritic copolymers have been studied, albeit less extensively than other nanostructures, in relation to dental composite applications. Combinations of specific polymers to optimize efficacy of restorative applications have been reported.

Nanotechnology applications in dentistry

Applications of nanotechnology in the dental field are varied, including the advanced visualization of dental structures, improvement in the physical properties of materials, mimicking the natural processes in tooth development, and in the use of specialized nanomachines called nanorobots to perform routine dental procedures.

Nanocharacterization in dentistry

Based on their unique capabilities and resolution, nanoscale science probes surfaces using forces, displacement resolutions, and concentrations on the piconewton, nanometer, and picomolar scales, respectively. Studying dental structures and surfaces from a nanoscale perspective might lead to better understanding the structure and function–physiological relationship of dental surfaces.

Nanoscale topology and quantitative biomechanical or biophysical analyses of dental surfaces are of significant interest. In particular, using atomic force microscopy techniques,[23] diseases, such as dental caries, tooth hypersensitivity, peridontitis, and oral cancer, can be quantified based on morphological, biophysical, and biochemical nanoscale properties of the tooth surface itself and dental materials, and might lead to better understanding the structure and function–physiological relationship of dental surfaces. Using nanocharacterization tools for oral fluids, such as saliva, a variety of oral diseases can be understood at the molecular and cellular levels, and thereby prevented. Advanced nanocharacterization techniques are relevant for the elucidation of underlying physiochemical mechanisms favoring biocompatibility and osseointegration of dental implants.

Nanomaterials

Various nanostructures are manipulated together to either modify the existing dental materials or produce the newer better alternatives.

Nanocomposites

A common trend in this ongoing discussion is the capability to operate on a scale small enough to interact with intracellular components, including DNA. Operating on a stage this minute enables tooth structure restoration at a level that offers progressively closer approximation of its individual anatomic structures. The ever-shrinking size of the nanoparticles in RBC ceramic restorative systems continues in a progression that might be envisioned as "mimicking" actual tooth structure. The nano-agglomerated discrete nanoparticles are homogeneously distributed in resins or coatings to produce nanocomposites. The nanofillers include an aluminosilicate powder with a mean particle size of approximately 80 nm and a 1:4 ratio of alumina to silica.[24]

The nanofiller with a refractive index of 1.503 has esthetic and strength advantages over conventional microfilled and hybrid RBC systems, primarily in terms of smoothness, polishability, and precision of shade characterization, plus flexural strength and microhardness, similar to those of the better-performing posterior RBC. Although the long-term benefits of these nanocomposites remain to be determined through clinical studies, the laboratory findings suggest a promising future.

Restorative materials advances

The polyhedral oligomeric silsesquioxane (POSS)[25] molecule can be used in dental applications to: (a) improve adhesion at the interface between the restorative material and the tooth structure; (b) reduce tooth sensitivity through sealing the tubules with POSS nano-sized molecules; and (c) provide structural reinforcement, toughness, and processability.

Ormoceris (Fraunhofer-Gesellschaft, Munich, Germany) is an acronym for organically modified ceramics. Ormocers represent a new technology based on sol-gel synthesis using particles comprising silicones, organic polymers, and ceramic glasses that is applicable to dental composites.[26] Ormocer composite technology is used in conjunction with nanoparticle fillers, such as ZrO_2, that are widely used in nanocomposite restorative systems.

Nano-sized $CaPO_4$-incorporated composites are used in the optimal delivery of molecules that facilitate tooth structure remineralization and forestall caries is an active area of nanostructure-based research. Much of this work involves nanoparticles in conjunction with RBC systems. Recent studies by Xu *et al.*[27–29] have evaluated the incorporation of nano-sized $CaPO_4$ particles with RBC, with a resulting improvement in stress-bearing capacity, as well as ion release that could inhibit caries.[28] Further investigation of this model using dicalcium phosphate anhydrous incorporated with nanosilica-fused whiskers found that it increased the strength of the RBC by as much as threefold while releasing $CaPO_4$. This release was greater with decreasing $CaPO_4$ particle size.[27] The authors hypothesize that such a system could provide a desirable combination of caries prevention and increased restoration strength.[27,29]

Materials for endodontic regeneration

Teeth with degenerated and necrosed pulps are routinely saved by root canal therapy. Although current treatment modalities offer high levels of success for many conditions, an ideal form of therapy might consist of regenerative approaches, in which diseased or necrotic pulp tissues are removed and replaced with healthy pulp tissues to revitalize teeth.

In their study, Fioretti *et al.*[30] showed that α-MSH (melanocortin peptides) possess anti-inflammatory properties and also promote the proliferation of pulpal fibroblasts. They reported the first use of nanostructured and functionalized multilayered films containing α-MSH as a new active biomaterial for endodontic regeneration.

Esthetic materials

With the combination of finishing and polishing procedures, a nanotechnology liquid polish application might provide a more glossy surface for resin composite restorations.[31]

Solutions

Nanosolutions produce unique and dispersible nanoparticles, which can be used in bonding agents. This ensures homogeneity and ensures that the adhesive is perfectly mixed every time.

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.

Dental biomimetics

The most interesting venue for speculation on the nanorestoration of tooth structure is that of nanotechnology mimicking processes that occur in nature (biomimetics), such as the formation of dental enamel. The central theme in the study of ways to mimic nature's already-efficient use of nanotechnology involves the cooperative interaction between self-assembled nanospheres of the proline-rich protein amelogenin (the most abundant protein in dental enamel) and the formation and directional orientation of HA crystals that compose enamel's hard-tissue mineral phase.[32] A recent *in vitro* study by Wang *et al.*[33] further elucidated mechanisms of interaction among amelogenin nanospheres, nanoparticles, and nanorods at critical points during the HA crystal-growth process. The results offer further evidence for cooperation in interfacial matching between organic and inorganic nanophases that might resemble processes that occur in actual enamel formation. With the understanding of nanoscale biological processes involved in tooth formation, nanorobotic manufacture and installation of a biologically autologous whole-replacement tooth that includes both mineral and cellular components – that is, complete dentition replacement therapy – should become feasible within the time and economic constraints of a typical office visit, through the use of an affordable desktop manufacturing facility, which would fabricate the new tooth, in the dentist's office.

Nanorobotics

New potential treatment opportunities in dentistry might include local anesthesia, dentition renaturalization, permanent hypersensitivity cures, complete orthodontic realignments during a 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 and acquire energy, sense, and manipulate their surroundings to achieve safe cytopenetration 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 might be controlled by an onboard nanocomputer that executes pre-programmed instructions in response to local sensor stimuli. Alternatively, the dentist might issue strategic instructions by transmitting orders directly to *in vivo* nanorobots via acoustic signals or other means.[3,4]

Local nano-anesthesia

One of the most common procedures in dentistry is the injection of local anesthesia, which can be a long procedure, causing patient discomfort and many associated complications. To induce oral anesthesia in the era of the nanodentist, professionals will install a colloidal suspension containing millions of active analgesic micrometer-sized dental nanorobot particles on the patient's gingivae. After contacting the surface of the crown or mucosa, the moving nanorobots reach dentin by migrating into the gingival sulcus and passing painlessly through the lamina propria or the 1- or 3-μm-thick layer of loose tissue at the cementodental junction.

On reaching the dentin, the nanorobots enter dentinal tubular holes that are 1–4 μm in diameter and proceed towards the pulp, guided by a combination of chemical gradients, temperature differentials, and even the position of navigation, all under the control of the onboard nanocomputer, as directed by the dentist. There are many pathways for the nanorobots to travel from dentin to pulp. Because of different tubular branching patterns, tubular density might present significant challenges to navigation. Assuming a total path length of approximately 10 mm from the tooth surface to the pulp and a modest travel speed of approximately 100 μm/sec, nanorobots can complete the journey into the pulp chamber in approximately 100 sec. Once installed in the pulp, having established control over nerve impulse traffic, the analgesic dental nanorobots might be commanded by the dentist to shut down all sensitivity in the tooth that requires treatment. When the dentist passes the icon for the desired tooth on the handheld controlled display monitor, the tooth is immediately anesthetized. After the oral procedure is completed, the dentist orders the nanorobots via the same acoustic data links to restore all sensation, relinquish control of nerve traffic, to retract from the tooth via a similar path. This analgesic technique is patient friendly, as it reduces anxiety, needle phobia, and most importantly, is a quick and completely reversible action.[4]

Dental hypersensitivity

Dentin hypersensitivity is a pathological phenomenon. It is caused by pressure-transmitted hydrodynamically to the pulp. Mainly hypersensitive teeth have dentinal tubules with surface densities that are eight times higher than those of non-sensitive teeth. Dental nanorobots can selectively and precisely occlude the specific tubules within 1 min, offering patients a quick and permanent cure.[4]

Orthodontic nanorobots

Orthodontic nanorobots can directly manipulate the periodontal tissue, including gingival, periodontal ligament, cemental, and alveolar tissues, 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.

Tooth durability and appearance

In nanodentistry, sapphire, a nanostructured composite material, increases tooth durability and appearance. Upper enamel layers are replaced by coherently bonded artificial materials, such as sapphire. This material has 100–200 times the hardness and failure strength than ceramic. Like enamel, sapphire is somewhat susceptible to acid corrosion. Sapphire has the best-standard whitening sealant and can be used as a cosmetic alternative.

Dentifrobots

Properly configured dentifrobots could identify and destroy pathogenic bacteria residing in the plaque and elsewhere, while allowing the 500 or so species of harmless oral microflora to flourish in a healthy ecosystem. Dentifrobots would also provide a continuous barrier to halitosis, since bacterial putrefaction is the central metabolic process involved in oral malodor.[34]

Renaturalization procedures

Dentition renaturalization procedures might become a popular addition to typical dental practice, providing perfect treatment methods for esthetic dentistry. This trend might begin with patients who desire to have their old dental amalgams excavated and their teeth remanufactured with native biological materials. However, demand will grow for full coronal renaturalization procedures, in which all fillings, crowns, and other 20th century modifications to the visible dentition are removed, with the affected teeth remanufactured to become indistinguishable from the original teeth.

Safety issues

While nanomaterials and nanotechnologies are expected to yield numerous health and health-care advances, such as more targeted methods of delivering drugs, new cancer therapies, and methods of early detection of diseases, they also might have unwanted effects. The increased rate of absorption is the main concern associated with manufactured nanoparticles.

When materials are made into nanoparticles, their surface area:volume ratio increases. The greater specific surface area (surface area/unit weight) might lead to increased rates of absorption through the skin, lungs, or digestive tract, and might cause unwanted effects to the lungs, as well as other organs. Apart from what occurs if non-degradable or slowly degradable nanoparticles accumulate in organs, another concern is their potential interaction with biological processes inside the body; because of their large surface, nanoparticles, upon exposure to tissue and fluids, will immediately absorb onto their surface some of the macromolecules they encounter. However, the particles must be absorbed in sufficient quantities in order to pose a health risk. The large number of variables influencing toxicity means that it is difficult to generalize the health risks associated with exposure to nanomaterials; each new nanomaterial must be assessed individually, and all material properties must be taken into account. As the use of nanomaterials increases worldwide, concerns for worker and user safety are mounting. To address such concerns, the Swedish Karolinska Institute conducted a study in which various nanoparticles were introduced to human lung epithelial cells. The results, released in 2008, showed that iron oxide nanoparticles caused little DNA damage and were non-toxic. Zinc oxide nanoparticles were slightly worse. Titanium dioxide caused only DNA damage; carbon nanotubes caused DNA damage at low levels. Copper oxide was found to be the worst offender, and was the only nanomaterial identified by the researchers as a clear health risk.[35] The National Institute for Occupational Safety and Health is conducting research on how nanoparticles interact with the body's systems and how workers might be exposed to nano-sized particles in the manufacturing or industrial use of nanomaterials.

Conclusion

As with all technologies, nanotechnology carries a significant potential for misuse and abuse on a scale and scope never seen before. Nanodevices cannot be seen, yet possess powerful capabilities. They have the potential to bring about significant benefits, such as improved health, better use of natural resources, and reduced environmental pollution. At present, applied nanotechnology to medicine and dentistry is in its infancy, with most of the research at the basic science level, as the field attempts to organize itself. As such, viable clinical applications are still years away, but despite this the current pace of development is impressive. Nanotechnology has the potential to provide controlled release devices with autonomous operation guided by need. Applications of nanotechnologies in medicine are especially promising, and such areas as disease diagnosis, drug delivery targeted at specific sites in the body, and molecular imaging are being intensively investigated.

Nanodentistry still faces many significant challenges in realizing its tremendous potential. Basic engineering problems from precise positioning and assembly of molecular-scale parts to economical mass production techniques to biocompatibility, and the simultaneous coordination of the activities of a large number of independent micrometer-scale robots is being investigated. Nanodentistry will give a new vision to comprehensive oral health care, as trends of oral health have been changing to more preventive intervention than a curative and restorative procedure. This science might sound like a fiction now, but nanodentistry has strong potential to revolutionize dentists to diagnose and treat diseases in the future. It opens up new ways for vast, abundant research work. Nanotechnology will change dentistry, health care, and human life more profoundly than other developments. However, at the same time, there will be increased social issues of public acceptance, ethics, regulation, and human safety that must be addressed before molecular nanotechnology can enter the modern medical and dental armamentarium.

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