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NANOTECHNOLOGY AND ITS APPLICATIONS IN THE FIELD OF MEDICINE

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ABSTRACT

Nanotechnology is the design, characterization, production and application of structures, devices and systems by controlling shape and size on a nanometer scale. Nanoparticles have different physical and chemical characteristics compared to their larger equivalents because of a very high surface to mass ratio, physical activity and chemical stability. Nanoparticles can be broadly grouped as organic and inorganic nanoparticles. Due to various advancements in nano technology it has been used in the field of medicine like delivering drug across blood barrier system, targeted drug delivery system, repair and regeneration of tissues, hearing and vision, disease diagnosis and health monitoring. Magnetic nanoparticles are also used in targeted therapy where a cytotoxic drug is attached to a biocompatible magnetic nanoparticle. Nanoparticles have also been incorporated in cloth which has shown promise to be sterile and thus helping in minimizing infections. Bioremediation of radioactive wastes from nuclear power plants and nuclear weapon production, such as uranium has been achieved using nanoparticles. Nanoparticles have more suface to mass ratio when compared to conventional normal forms. Nanoparticles are less toxic than their conventional normal form. Nanoparticles can cross blood-brain barrier system and can penetrate through deep tissues due to its smaller size as that of biological molecules within the body.

KEY WORDS: Nanoparticles, nanometer scale, targeted drug delivery.

INTRODUCTION

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales. Nanotechnology is the design, characterization, production and application of structures, devices and systems by controlling shape and size on a nanometer scale. In nanotechnology, a nanoparticle (10^{-9} nm) is defined as a small object that behaves as a whole unit in terms of its transport and properties. The term nanotechnology was created by Norio Taniguchi of Tokyo University in 1974.[1] A nanometer (nm) is one thousand millionth of a meter. A single human hair is about 80,000 nm wide, a red cell is approximately 7,000 nm wide, a DNA molecule is about 2 to 2.5 nm and a water molecule is almost 0.3 nm.

Nanoparticles have different physical and chemical characteristics compared to their larger equivalents because of a very high surface to mass ratio, physical activity and chemical stability. Moreover, below 50 nm, the laws of classical physics give way to quantum effects, provoking different optical, electrical and magnetic behaviours. The small size of nanoparticles allows for penetration inside tissues and even enables them to cross cell membranes. Nanoparticles can bypass conventional physiological ways of nutrient and drug distribution and transport across tissue and cell membranes, as well as protect compounds against destruction prior to reaching their targets.

Nanoparticles had been used in the field of drug delivery since 1950's. One of the pioneers in this field was Professor Peter Paul Speiser. His research group at first investigated polyacrylic beads for oral administration, then focused on micron microcapsules and in the late 1960's developed the first nanoparticles for drug delivery purposes and for vaccines. In 1977, 5-fluorouracil was bound to the albumin nanoparticles, and found denaturation temperature dependent differences in drug release as well as in the body distribution in mice after intravenous tail vein injection. [2] An increase in life span was observed after intraperitoneal injection of the nanoparticles into Ehrlich Ascites Carcinoma-bearing mice.[3]

CLASSIFICATION OF NANOPARTICLES

Nanoparticles can be broadly grouped into two: namely organic and inorganic nanoparticles. Organic nanoparticles may include carbon nanoparticles (fullerenes) while some of the inorganic nanoparticles may include magnetic nanoparticles, noble metal nanoparticles (like gold and silver) and semiconductor nanoparticles (like titanium dioxide and zinc oxide).

There is a growing interest in inorganic nanoparticles as they provide superior material properties with functional versatility. Due to their size features and advantages over available chemical imaging drug agents and drugs, inorganic nanoparticles have been examined as potential tools for medical imaging as well as for treating diseases. Inorganic nanomaterials have been widely used for cellular delivery due to their versatile features like wide availability, rich functionality, good biocompatibility, capability of targeted drug delivery and controlled release of drugs. [4] For example mesoporous silica when combined with molecular machines proved to be excellent imaging and drug releasing systems. Gold nanoparticles have been used extensively in imaging, as drug carriers and in thermo therapy of biological targets.[5]

APPLICATION OF NANOPARTICLES IN MEDICINE

Nanotechnology has a wide range of applications in the fields of biology, medicine, optical, electrical, mechanical, optoelectronics etc. Due to various advancements in nano technology it has been used in the field of medicine like delivering drug across blood barrier system, targeted drug delivery system etc.

How it works

Nanoscale devices are hundred to ten thousand times smaller than human cells and are similar in size to large biological molecules such as enzymes and receptors, so that it can readily interact on both the surface and inside of cells and provides opportunity to detect disease at the earliest stage itself. Hemoglobin is approximately 5 nm in diameter, while a quantum dot is about the same size as a small protein (<10 nm) and some viruses measure less than 100 nm. Devices smaller than 50 nm can easily enter most cells, while those smaller than 20 nm can move out of blood vessels as they circulate through the body. Nanoparticles have some of the same properties as that of natural nanoscale structures, which is helpful to develop artificial nanoparticles just as naturally occurring biological nanostructures such as white blood cells that sense and repair damage to the organism. By gaining access to so many areas of the body, they have the potential to detect disease and deliver treatment in new ways.[6]

Drug delivery

This may be the most profitable application of nanotechnology in medicine. Drugs need to be protected during their transit through the body to the target, to maintain their biological and chemical properties or to stop them damaging the parts of the body they travel through.

Once a drug arrives at its destination, it needs to be released at an appropriate rate for it to be effective. This process is called encapsulation, and nanotechnology can improve both the diffusion and degradation characteristics of the encapsulation material, allowing the drug to travel efficiently to the target and be released in an optimal way. Nanoparticle encapsulation is also being investigated for the treatment of neurological disorders to deliver therapeutic molecules directly to the central nervous system beyond the blood-brain barrier, and to the eye beyond the blood-retina barrier. Applications could include Parkinson's, Huntington's chorea, Alzheimer's and diseases of the eye. Nano-capsules, dendrimers (tiny brush-like spheres made of branched polymers) and "buckyballs" (soccerball shaped structures made of 60 carbon atoms) for slow, sustained drug release systems. Nanotechnology could also potentially reduce transportation costs and even required dosages by improving shelf-life, thermo-stability and resistance to changes in humidity of existing medications.[6]

Repair and replacement

Damaged tissues and organs are often replaced by artificial substitutes, and nanotechnology offers a range of new biocompatible coatings for the implants that improves their adhesion, durability and lifespan. New types of nanomaterials are being evaluated as implant coatings to improve interface properties. For example, nanopolymers can be used to coat devices in contact with blood (eg, artificial hearts, catheters) to disperse clots or prevent their formation. Nanomaterials and nanotechnology fabrication techniques are being investigated as tissue regeneration scaffolds. The ultimate goal is to grow large complex organs. Examples include nanoscale polymers moulded into heart valves and polymer nanocomposites for bone scaffolds. Nanostructures are promising for temporary implants, e.g. that biodegrade and do not have to be removed in a subsequent operation. Research is also being done on a flexible nanofiber membrane mesh that can be applied to heart tissue in open-heart surgery. The mesh can be infused with antibiotics, painkillers and medicines in small quantities and directly applied to internal tissues.

Subcutaneous chips are already being developed to continuously monitor key body parameters including pulse, temperature and blood glucose. Another application uses optical microsensors implanted into subdermal or deep tissue to monitor tissue circulation after surgery, while a third type of sensor uses MEMS (Micro Electro Mechanical System) devices and accelerometers to measure strain, acceleration, angular rate and related parameters for monitoring and treating paralysed limbs and to improve the design of artificial limbs. Implantable sensors can also work with devices that administer treatment automatically if required, e.g. fluid injection systems to dispense drugs. Initial applications may include chemotherapy that directly targets tumors in the colon and are programmed to dispense precise amounts of medication at convenient times, such as after a patient has fallen asleep. Sensors that monitor the heart's activity level can also work with an implantable defibrillator to regulate heartbeats.[6]

Hearing and Vision

Nano and related micro technologies are being used to develop a new generation of smaller and potentially more powerful devices to restore lost vision and hearing. One approach uses a miniature video camera attached to a blind person's glasses to capture visual signals processed by a microcomputer worn on the belt and transmitted to an array of electrodes placed in the eye. Another approach uses of a subretinal implant designed to replace photoreceptors in the retina. The implant uses a microelectrode array powered by up to 3500 microscopic solar cells. For hearing, an implanted transducer is pressure-fitted onto a bone in the inner ear, causing the bones to vibrate and move the fluid in the inner ear, which stimulates the auditory nerve. An array at the tip of the device uses up to 128 electrodes, five times higher than current devices, to stimulate a fuller range of sounds. The implant is connected to a small microprocessor and a microphone in a wearable device that clips behind the ear. This captures and translates sounds into electric pulses transmitted by wire through a tiny hole made in the middle ear.[6]

Disease diagnosis and screening

Technologies include the "lab-on-a-chip", which offers all the diagnostic functions of a medical laboratory and other biosensors based on nanotubes, wires, magnetic particles and semiconductor crystals (quantum dots). These inexpensive, hand-held diagnostic kits detect the presence of several pathogens at once and could be used for wide range screening in small peripheral clinics.[6]

Health monitoring

Nano-devices are being developed to keep track of daily changes in physiological variables such as the levels of glucose, of carbon dioxide, and of cholesterol, without the need for drawing blood in a hospital setting. For example, patients suffering from diabetes would know at any given time the concentration of sugar in their blood, similarly patients with heart diseases would be able to monitor their cholesterol levels constantly.[6]

OTHER APPLICATIONS OF NANOTECHNOLOGY

Silver nanoparticles have also been used for a number of applications such as nonlinear optics, spectrally selective coating for solar energy absorption, biolabelling and antibacterial activities. Silver nanoparticles have shown promise against gram positive *Staphylococcus aureus*. The interaction of silver nanoparticles with HIV I has been demonstrated in vitro. It was shown that the exposed sulfur binding residues of the glycoprotein knobs were attractive sites for nanoparticle interaction and that the silver nanoparticles had preferential binding to the gp 120 glycoprotein knobs. Due to this interaction, it was found that the silver nanoparticles inhibited the binding of the virus to the host cells in vitro.[7]

Nanoparticles have also been incorporated in cloth which has shown promise to be sterile and thus helping in minimizing infections. Metal nanoparticle embedded paints have been synthesized using vegetable oils and have been found to have good antibacterial activity.[8] Current research is going on regarding the use of magnetic nanoparticles in the detoxification of military personnel in case of biochemical warfare. It is hypothesized that by utilizing the magnetic field gradient, toxins can be removed from the body. Enhanced catalytic properties of surfaces of nano ceramics or those of noble metals like platinum and gold are used in the destruction of toxins and other hazardous chemicals.[9] The high reactivity of Titania nanoparticles either on their own or when illuminated by UV light have been used for bactericidal purposes in filters.

Magnetic nanoparticles are also used in targeted therapy where a cytotoxic drug is attached to a biocompatible magnetic nanoparticle. When these particles circulate in the bloodstream, external magnetic fields are used to concentrate the complex at a specific target site within the body. Once the complex is concentrated in the target, the drug can be released by enzymatic activity or by changes in pH or temperature and are taken up by the tumour cells.[10]

Porous nanoparticles have also been used in cancer therapy where the hydrophobic version of a dye molecule is trapped inside the Ormosil nanoparticle. The dye is used to generate atomic oxygen which is taken up more by the cancer cells when compared to the healthy tissue. When the dye is not entrapped, it travels to the eyes and skin making the patient sensitive to light. Entrapment of the dye inside the nanoparticle ensures that the dye does not migrate to other parts and also the oxygen generating ability is not affected.

The magnetotactic bacterium was found to have about 20 magnetic crystals with a size range of 35- 120nm diameter. The crystals serve as a miniature compass and align the bacteria with the external magnetic field. This enables the bacterium to navigate with respect to the earth's magnetic field towards their ideal environment. These bacteria immobilize heavy metals from a surrounding solution and can be separated by applying a low intensity magnetic field. This principle can be extended to develop a process for the removal of heavy metals from waste water.[11]

Bioremediation of radioactive wastes from nuclear power plants and nuclear weapon production, such as uranium has been achieved using nanoparticles. Cells and S layer proteins of *Bacillus sphaericus* JG A12 have been found to have special capabilities for the clean up of uranium contaminated waste waters.[12]

Magnetosome particles isolated from magnetotactic bacteria have been used as a carrier for the immobilization of bioactive substances such as enzymes, DNA, RNA and antibodies.[13]

Gold nanoparticles are widely used in various fields such as photonics, catalysis, electronics and biomedicine due to their unique properties. *Escherichia coli* had been used to synthesize gold nanoparticles and it has been found that these nanoparticles are bound to the surface of the bacteria. This composite may be used for realizing the direct electrochemistry of haemoglobin.[14]

CONCLUSION

Nanotechnology is very useful in the field of medicine and it has provided many new techniques to screen and diagnose disease at its early stage and also to treat the disease by acting on the targeted site, to replace and regenerate new tissues, as hearing and vision aid, regular monitoring of health etc. Nanoparticles have more suface to mass ratio when compared to conventional normal forms. Nanoparticles are less toxic than their conventional normal form. Nanotechnology is very helpful to reduce the therapeutic dosage level of drugs without affecting the therapeutic effect. Nanoparticles can cross blood-brain barrier system and can penetrate through deep tissues due to its smaller size as that of biological molecules within the body. Nanoscale materials have been used for decades in applications ranging from window glass and sunglasses to car bumpers and paints. Now, however the convergence of scientific disciplines is leading to a multiplication of applications in materials manufacturing, computer chips, medical diagnosis, health care, energy, biotechnology, space exploration, security and so on. Hence, nanotechnology is expected to have a significant impact on our economy and society within the next 10 to 15 years.

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