Volume 1 Issue 2 2012

ISSN: 2320- 4818

Available online at: www. jsirjournal.com

JOURNAL OF SCIENTIFIC & INNOVATIVE RESEARCH

Therapeutic application of Nanotechnology: An overview

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Abstract: The emerging field of nanotechnology involves scientists from many different disciplines, including physicists, chemists, engineers and biologists. Nanotechnology is the creation of useful materials, devices or systems through the manipulation of such miniscule matter. Matter behaves differently on the nanoscale than it does at larger levels. The factors that govern larger systems do not necessarily apply on the nanoscale. Today, much of the science on the nanoscale is basic research, designed to reach a better understanding of how matter behaves on this small scale. Nanostructures can be so small that the body may clear them too rapidly for them to be effective in detection or imaging. Larger nanoparticles may accumulate in vital organs, creating a toxicity problem. Finally, the review will raise awareness of the physiological challenges for the application of nanotechnology.

Keywords: Nanotechnology, Nanomedicine, Cardiac therapy, Human risk

Introduction:

Richard Feynman first in 1959 provided the basis for the concept of Nanotechnology. However the word Nanotechnology was coined by Professor Noro Taniguchi of Tokyo University of Science in 1974. Nanotechnology refers to molecular devices in the range of 1 to 100 nanometers. One nanometer (1nm) is one billionth or 107 of a metre or 1/80,000 the width of a human hair or about combined diameter of 10 hydrogen atoms.[1, 2]

Nanotechnology can be defined as the science and engineering involved in the design, synthesis, characterization and application of materials and devices whose smallest functional organization in at least one dimension is on the nanometer scale (one-billionth of a meter).[3,4] In the past few years nanotechnology has grown by leaps and bounds, and this multidisciplinary scientific field is undergoing explosive development.[5-7] It can prove to be a boon for human health care, because nanoscience and nanotechnologies have a huge potential to bring benefits in areas as diverse as drug development, water decontamination, information and communication technologies, and the production of stronger, lighter materials. Human health-care nanotechnology research can definitely result in immense health benefits. The genesis of nanotechnology can be traced to the promise of revolutionary advances across medicine, communications, genomics, and robotics. A complete list of the potential applications of nanotechnology is too vast and diverse to discuss in detail, but without doubt, one of the greatest values of nanotechnology will be in the development of new and effective medical treatments.[3, 8-12] This review focuses on the potential of nanotechnology in medicine, including the development of nanoparticles for drug and gene delivery and diagnostics. These technologies will extend the limits of current molecular diagnostics and permit accurate diagnosis as well as the development of personalized medicine.

History of nanotechnology:

The prefix "nano" derives from the Greek word for "dwarf." One nanometer (nm) is equal to one-billionth of a meter, or about the width of 6 carbon atoms or 10 water molecules. A human hair is approximately 80,000 nm wide, and a red blood cell is approximately 7000 nm wide. Atoms are smaller than 1 nm, whereas many molecules including some proteins range between 1 nm and larger.[13]

Advantages of drug delivery to disease sites:

The pathophysiological condition and anatomical changes of diseased or inflamed tissues offers many advantages for the delivery of various nanotechnological products. D rug targeting can be achieved by taking advantage of the distinct pathophysiological features of diseased tissues.[14]

The therapeutic value of many promising drugs for the treatment of various neurological disorders is diminished by the presence of the blood-brain barrier.[15]The blood-brain barrier is a unique membrane that tightly segregates the brain from the circulating blood.[16] Thus, drug delivery to this organ is a challenge, because the brain benefits from very efficient protection. Nanotechnology offers a solution for using the numerous chemical entities for treating brain disorders that are not clinically useful because of the presence of the blood-brain barrier. Nanoparticles can be effectively used to deliver relevant drugs to the brain.[17, 18] Drug loading onto nanoparticles modifies cell and tissue distribution and leads to a more selective delivery of biologically active compounds to improve drug efficacy and reduces drug toxicity.[19-21] Thus, various nanosystems can be successfully used as new drug carriers for brain delivery.

Therapeutical applications of nanotechnology:

1. Nanotechnology in drug delivery:

From nanotechnology there is only one step to nanomedicine, which may be defined as the monitoring, repair, construction, and control of human biological systems at the molecular level, using engineered nanodevices and nanostructures.[3, 11, 13, 22] It can also be regarded as another implementation of nanotechnology in the field of medical sciences and diagnostics. One of the most important issues is the proper distribution of drugs and other therapeutic agents within the patient's body.[9, 22-24]

During the past two decades, however, researchers involved in the development of pharmaceuticals have understood that drug delivery is a fundamental part of drug development, and a wide range of drug delivery systems has thus been designed. The final aim of pharmaceutical research is the delivery of any drugs at the right time in a safe and reproducible manner to a specific target at the required level.[4, 14]

Applications of nanotechnologies in medicine are especially promising, and areas such as disease diagnosis, drug delivery targeted at specific sites in the body, and molecular imaging are being intensively investigated and some products undergoing clinical trials.[9,11,25,26] Nanotechnology is relatively new, and although the full scope of contributions of these technological advances in the field of human health care remains unexplored, recent advances suggest that nanotechnology will have a profound impact on disease prevention, diagnosis, and treatment.[4,6,23,26]

2. Nanotechnology in gene delivery:

Gene therapy is a recently introduced method for treatment or prevention of genetic disorders by correcting defective genes responsible for disease development based on the delivery of repaired genes or the replacement of incorrect ones.[27-30] The most common approach for correcting faulty genes is insertion of a normal gene into a nonspecific location within the genome to replace a nonfunctional gene. An abnormal gene could also be swapped for a normal gene through homologous recombination or repaired through selective reverse mutation, which returns the gene to its normal function.[31-33]

Applications of nanotechnological tools in human gene therapy has been reviewed widely by Davis, who described nonviral vectors based on nanoparticles (usually 50-500 nm in size) that were already tested to transport plasmid DNA. He emphasized that nanotechnology in gene therapy would be applied to replace the currently used viral vectors by potentially less immunogenic nanosize gene carriers. So delivery of repaired genes or the replacement of incorrect genes are fields in which nanoscale objects could be introduced successfully.[34]

3. Nanotechnology as a tool in imaging:

Noninvasive imaging techniques have had a major impact in medicine over the past 25 years or so. The current drive in developing techniques such as functional magnetic resonance imaging is to enhance spatial resolution and contrast agents. Nanotechnology has a potential to transform the field of medicine, because it offers novel opportunities for sensing clinically relevant markers, molecular disease imaging, and tools for therapeutic intervention.[35]

Nanotechnologies already afford the possibility of intracellular imaging through attachment of quantum dots (QDs) or synthetic chromophores to selected molecules, for example proteins, or by the incorporation of naturally occurring fluorescent proteins that, with optical techniques such as confocal microscopy and correlation imaging, allow intracellular biochemical processes to be investigated directly. QDs are semiconductor nanocrystals with unique optical and electrical properties.[26, 35, 36]

4. Nanotechnology for molecular diagnostics:

Nanobiotechnology in molecular diagnostics fall under the broad category of biochips/microarrays but are more correctly termed nanochips and nanoarrays. Biochips constructed with microelectromechanical systems are on a micron scale and related to micromanipulation, whereas nanotechnology-based chips are on a nanoscale and related to nanomanipulation.[37, 38]

Nanotechnologies also provide labelfree detection. Nanotechnology is thus being applied to overcome some of the limitations of biochip technology.[23, 37, 39-41]

5. Nanotechnology in cardiac therapy:

Cardiac diseases are the major cause of mortality, morbidity, and disability. Ever more people are dying of various cardiac problems including atherosclerosis, myocardial infarction, arrhythmias, ischemic heart disease, and restenosis.[40] Oral and systemic administration of drugs, though effective, does not provide appropriate therapeutic drug levels in the target arteries for sufficient periods of time. Nanotechnology-based tools can be effectively used to treat the cardiovascular diseases. These tools can be used in the areas of diagnosis, imaging, and tissue engineering.[43]

Miniaturized nanoscale sensors like QDs, nanocrystals, and nanobarcodes can sense and monitor biological signals such as the release of proteins or antibodies in response to cardiac or inflammatory events.[36] Nanotechnology can also help in revealing the mechanisms involved in various cardiac diseases. Therefore, researchers have a great hope that nanotechnology-based localized drug therapy using sustained-release drug delivery systems could be more effective, because it can provide higher and prolonged drug levels in the target tissues without causing systemic toxicity.[44]

6. Nanotechnology in dental care:

Nanotechnology will have future medical applications in the field of nanodentistry.

Nanodentistry will make it possible to maintain near-perfect oral health through the use of nanomaterials,[45, 46] biotechnology[47-50] and nanorobotics. Through this it will be possible to provide high-quality dental care to the millions of the world's population who currently receive no significant dental care.[51, 52]

In the years to come it will be possible through nanodentistry to induce local anesthesia. A colloidal suspension containing millions of active analgesic dental nanorobotic particles could be instilled on the patient's gingivae. These nanorobots, after contacting the surface of the crown or mucosa, reach the dentin by migrating into the gingival sulcus and pass painlessly to the target site.[53-55]

Another pathological phenomenon that may be benefited by nanodental treatment is dentin hypersensitivity.[52] Dentin hypersensitivity is a common condition of transient tooth pain associated with a variety of exogenous stimuli. There is substantial variation in the response to such stimuli from one person to another. Except for sensitivity associated with tooth bleaching or other tooth pathology, the clinical cause of dentin hypersensitivity is exposed dentinal tubules as a result of gingival recession and subsequent loss of cementum on root surfaces.[56-58]

7. Nanotechnology in orthopedic applications:

An ageing population and an increased occurrence of sports-related injuries have made musculoskeletal disorders one of the major health concerns. Current treatment modalities include orthopedic implants used for internal fixing of fractured bones, but these are limited by the large number of implant failures. In addition, these engineered implants are stiffer than those of cortical bones, and removal of the implants require a second operation. Besides, the polymers used suffer from the drawbacks of loss of mechanical strength within a time interval and also development of a sterile sinus at the site of implantation. Biomaterials proposed as ideal scaffolds for cell growth should be biocompatible, osteoinductive, osteoconductive, integrative, porous, and mechanically compatible with native bone to fulfill their desired role as bone implants and substitutes. Nanotechnology can provide an alternative platform with higher mechanical strength, enhanced bioactivity, and resorbability in improving the quality of life of patients who suffer from debilitating bone fractures. [59, 60]

Nanomaterials, nanopolymers, carbon nanofibers, nanotubes, and nanocomposites of ceramics will also lead to more efficient deposition of calcium-containing minerals on the implants. Recent studies have demonstrated that the adsorption and conformation of proteins that mediate specific osteoblast adhesion (such as fibronectin and vitronectin) are enhanced on nanospaced materials like 3D nanofibrous scaffolds.[61-63]

8. Nanotechnology in Cancer therapy:

Nanotechnology is considered to be an emerging, disruptive technology that will have significant impact in all industrial sectors and across-the-board applications in cancer research. There has been tremendous investment in this area and an explosion of research and development efforts in recent years, particularly in the area of cancer research. At the National Institutes of Health, nanomedicine is one of the priority areas under its Roadmap Initiatives.[64]

It is believed that localization and accumulation of nanoparticles preferentially in tumors may be achieved by enhanced permeability and retention of nanoparticles based on passive extravasation of particles b400 nm in most tumors.[65-67]

9. Nanotechnology in Alzheimer's disease:

Alzheimer's disease (AD) represents the most common form of dementia worldwide, affecting more than 35 million people. Advances in nanotechnology are beginning to exert a significant impact in neurology. These approaches, which are often based on the design and engineering of a plethora of nanoparticulate entities with high specificity for brain capillary endothelial cells, are currently being applied to early AD diagnosis and treatment.[68-71]

10. Nanotechnology as a risk to human health:

Although the benefits of nanotechnology are widely publicized, discussion of the potential effects of their widespread use in consumer and industrial products is just beginning. Both pioneers of nanotechnology and its opponents are finding it extremely hard to argue their case because of the limited information available to support one side or the other. Given the rapid rate of development in this area and the amount of publicity it is attracting, it is not surprising that concerns should have been raised relating to the safety of nanomaterials in a variety of products. Some have drawn an analogy between high-aspect-ratio nanoparticles and asbestos fibers.[7, 72]

Carbon black nanoparticles have been implicated in interfering with cell signaling. There is work that demonstrates uses of DNA for the size separation of carbon nanotubes. The DNA strand just wraps around it if the tube diameter is right. Though excellent for the purposes of separation, this tendency raises some concerns over the consequences of carbon nanotubes entering the human body.[5, 73]

Conclusion:

Advancement in Nanotechnology & Targeted drug delivery will change the treatment approach in cancer patients. Greater understanding of the complex processes leading to disease may help in greater application of nanotechnology. Nanotechnology offers tailor-made therapeutics. Over the next couple of years it is widely anticipated that nanotechnology will continue to evolve and expand in many areas of life and science, and the achievements of nanotechnology will be applied in medical sciences, including diagnostics, drug delivery systems, and patient treatment.

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