Application Areas and Development Prospects of Nanomedicine

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Abstract--- *Nanotechnology has become a focus for scientific research and technological development along with related concepts such as nanomaterials, nanostructures and nanoparticles. Nanotechnology, that is, the development and use of nanometer-scale materials and tools, already has various applications in the electronics and other areas. The highest hopes, though, are for its use in biotechnology and in medicine, with direct impact both could have on health outcomes of future societies. The emerging nanomedicine discipline is bringing together nanotechnology and medicine to develop novel therapies and improve existing treatments. The atoms and molecules are engineered in nanomedicine to create nanostructures of the same size as biomolecules for contact with human cells. Through activating the body's own repair mechanisms, this technique offers a range of innovative medical approaches and "smart" therapies. It will improve early diagnosis and treatment of diseases like cancer, Alzheimer's, diabetes, cardiovascular and Parkinson's disorders. Preventive pharmaceutical drugs can then become a reality.*

Keywords--- *Drug delivery, Nanobiosensor, Nanomaterials, Nanomedicine, Nanoparticles, Nanostructures, Nanotechnology.*

I. INTRODUCTION

The term nanotechnology means the ability at the molecular, atomic, and supramolecular level to measure, design, and manipulate the materials to understand, generate, and apply structures and the systems with particular functions related to their size. Conventionally, nanotechnology refers to matter in size range of 1-10.0nm and is sometimes extended by including materials below the .1μm in size[1]. A key objective is to combine nanoparticles and incorporate them into organized structures to get usable materials. Various industry sectors have adopted nanotechnology for use in the fields of biotechnology, electronic storage systems, magnetic isolation and preconcentration of the target analytes and selective drug delivery, and as instruments for the delivery of genes and medicines[2]. Advancements in nanotechnology have led to the creation of modern nanomaterials, which physiochemical properties vary due to their higher surface-to-volume ratio from those of their larger counterparts[3]. Given the number of biological processes which occur at the nanometer scale, these novel properties make them ideal candidates for biomedical applications. Nanotechnology is a modern science and engineering discipline which has led to groundbreaking solutions in many medical fields. The developments of disease detection, diagnosis, and care are collectively referred as emerging field of "nanomedicine" with the ability to revolutionize patient or

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population-based health this century. With the aid of nanoparticles, curing diseases and contributing to our knowledge of their pathogenesis it is now possible to provide treatment at a molecular level[1], [3]. Nanomedicine can be seen as a modernization in molecular biology, incorporating genomics and proteomics advances on the way to a more personalized medicine.

Nanotechnology's effect on medicine can be seen primarily in medical procedures, drug-release techniques, and regenerative medicine. Diagnostic approaches are important for the early diagnosis of infections so they can be treated appropriately, mitigating collateral damage to the rest of the body[4]. It is well known how important imaging approaches are to detect, cure and monitor cancer, cardiovascular and neurological patients. Diagnostic methods based on utilization of nanoparticles offer a higher sensitivity and help early disease detection, offering better prognosis and the higher possibilities for successful treatment. Once the diagnosis has been identified, the battle against the disease continues, with medications playing a major role. There are many barriers to the development of new disease-fighting medicines[5]. Conventional medications suffer from the significant drawback of negative effects arising from the non-specificity of their operation, and from a loss of effectiveness because of improper or insufficient dosages, e.g. in anti-diabetic care and cancer chemotherapy. Nanotechnology provides the opportunity to design new cell-specific drugs and new drug-release mechanisms that selectively operate on specific objectives. It causes smaller but more effective doses to be given, reducing adverse effects[6]. Nanotechnology could also be used to refine medication compositions, improve drug solubility and modify pharmacokinetics in order to maintain the drug's release, thus increasing its bioavailability[1], [6].

1. Nanomedicine Applications

Requirements for nanomedicine are classified below into three interrelated areas: diagnostic/analytical devices, regenerative medicine and drug delivery (Figure 1)[1].

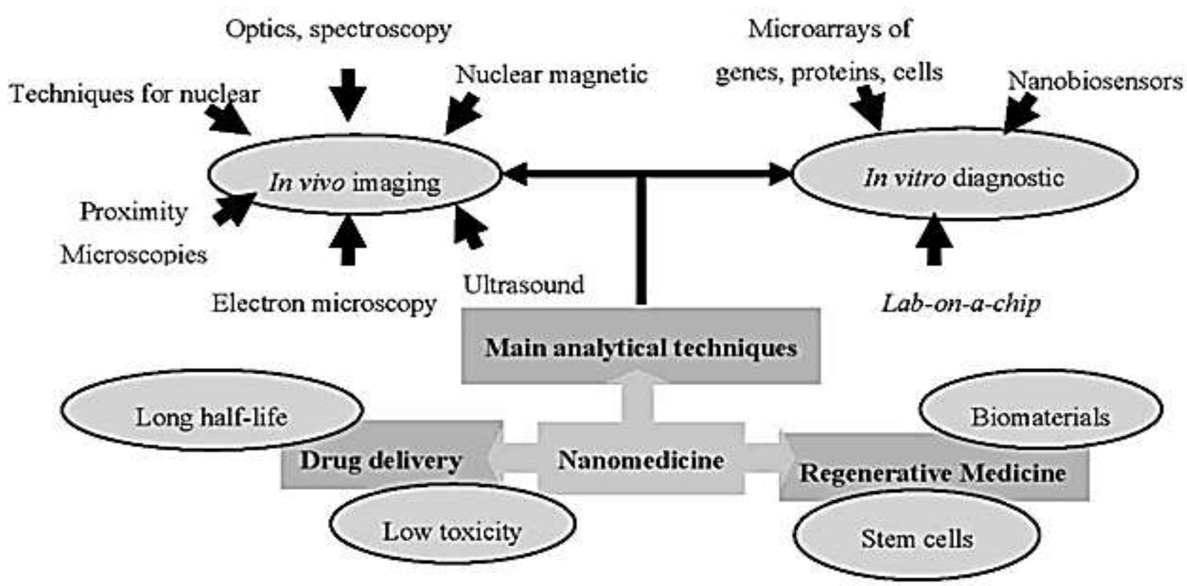

Figure 1: Nanomedicine application areas

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1.1. ***Analytical and Diagnostic Tools***

Current medical technology drawbacks mean that certain pathogens could only be identified when they are at a very advanced level. Nanodiagnostic is defined as the utilization of nanotechnology for the clinical diagnostic purposes. Nanodiagnostics was created to meet the needs for increased sensitivity in the clinical diagnosis and faster identification of diseases. Micro and nanobiotechnology use of medical diagnostics may be subdivided into the two wide categories: in vivo imaging and in vitro diagnostic instruments[7]. Work in this area is extremely multidisciplinary and there are close relationships between diagnostics, drug release and regenerative medicine, which are listed in the sections below.

I. In Vitro. Diagnostic Devices

The foundations for modern medicine had already been established in the mid 19th century with the cell being known as the center of health and sickness. Basic research was made compulsory in medicine to give a better understanding of the highly complex functioning of cells. The subsequent advances in methods for characterizing in vitro cells or cell compartments (e.g., optical and luminescence microscopy, electron microscopy, microscopy scanning microscope, and mass-spectrometry imaging) were profoundly important for the development of nanomedicine[2]. The incorporation and miniaturization of various functions into a single device, based on technologies developed from nanotechnology, has resulted in a new generation of instruments that are simpler, cheaper and faster, need no special skills and provide accurate readings. They require far smaller samples which imply less harmful and traumatic methods of extraction of samples and provide more accurate and complete biological data from the single measurement. Using these instruments in science has become commonplace and has improved our knowledge of the disease's molecular origin and helped identify potential therapeutic targets. In vitro diagnostic instruments include microarrays, nanobiosensors, and various elements biochips (DNA, proteins or cells)[2], [7].

1) Nanobiosensor

A nanobiosensor is defined as a compact analytical device incorporating the recognition elements of biological (nucleic acid, enzyme, antibody, receptor, tissue, and cell) or biomimetic (macrophage-inflammatory proteins, peptide nucleic acids, aptamers). Interaction between both the compound and microbes of interest and recognition element generates variations in one or more physicochemical properties (e.g. electron transfer, pH, heat, mass, potential, optical properties, etc.) which are identified by the transducer[8]. The resultant electronic signal indicates the presence and the concentration of the analyte of interest in the sample. To react to a single molecule's binding these sensors can be electronically gated. Nucleic acids, proteins, and ions were successfully measured using prototype sensors. They can function in the gas or liquid phase, opening up a huge range of downstream applications. Such detection systems use affordable low-voltage measurement techniques that immediately detect binding events, so there's no need for expensive difficult and time-consuming chemical marking, e.g. for fluorescent dyes, or for cumbersome and costly optical detection systems. Such sensors are therefore inexpensive to manufacture and compact[7]. Consequently, nanobiosensors are pioneering disease detection in vitro and have significant implications for the human health. They allow the healthcare professionals to calculate several clinical

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parameters simultaneously using a quick, reliable, and accurate method. Such instruments are also suitable for the high-throughput screening and for diagnosis in a single sample of a single disease in different samples, or of different diseases[1], [5], [8].

2) Microarrays

Another test device, the microarray, has become a popular tool in the research laboratories around the world. Microarray techniques have proved successful practical in almost every field of biomedical research since their first use. The advent of this new tool has allowed researchers to solve previously unwavering issues and identify new possible therapeutic goals. They use microarray techniques to classify cardinal growth and developmental factors and investigate the underlying genetic causes of various human illnesses[9]. Microarray-based experiments have huge potential to study the diseases like cancer, and to design and develop new drugs. In the analysis of various medical disorders like diabetes, breast cancer, atherosclerosis, colon cancer and pulmonary fibrosis, microarrays were commonly applied. Various forms of microarray have been produced for specific target materials that can be DNA, protein, cDNA, mR.NA, small molecules, tissues or any other quantitatively analyzable substance. A DNA collection includes a large number of the DNA molecules, organized orderly on a solid substratum to form a two-dimensional matrix of sequences[6], [7]. CDNA microarrays and microarrays of oligonucleotides, called "expression chips", are used for the microarray expression analysis, i.e. to determine the extent or volume of the expression of the gene in question. Microarrays of the single nucleotide polymorphism (SNP) identify polymorphisms or mutations in a sequence of genes[10]. This technique is being used to test the individual for the patterns of disease expression and to determine if individuals are prone to disease or not. Microarray comparative genomic hybridization is used to search for genomic gains and losses, or alterations in number of copies of gene involved in a condition. Tissue microarrays are one of the most useful methods in the microarray field, as they allow multiple tissue samples to simultaneously analyze protein, RNA, and DNA expression[9], [10].

II. In Vivo Imaging

Imaging devices can be classified by energy used to extract the visual information (positrons, X-rays, photons or sound waves), the spatial resolution (mesoscopic, macroscopic, or microscopic) or even the type of information collected (physiological, anatomic, cellular or molecular); Unlike a classic computed tomography (CT) imaging diagnosis, ultrasound or magnetic resonance imaging (MRI), nano-imaging or molecular imaging requires methods intended to collect genetic data to identify the origins of the illness in situ rather than its possible consequences[2]. Nanotechnology has made progress in diagnostic imaging, develop new technologies and increase the sensitivity and resolution of current techniques. Although these technologies only recently emerged, and only some of them are in preclinical and clinical use, they made it easier to in vivo study human biochemical processes in various organs, opening new horizons in the instrumental diagnostic medicine. Such technologies include single-photon emission C.T (SPE.CT), positron emission tomography (P.ET), fluorescence reflectance imaging, fibre-optic microscopy, fluorescence-mediated tomography (FM.T), optical frequency-domain imaging, laser-scanning confocal microscopy, multiphoton microscopy and bioluminescence imaging[1], [5].

1.2. Drug Delivery

Nanovehicles, nanoscale compounds utilized as a medicinal method and designed specifically to aggregate at the places of the body in which they are required to improve pharmacotherapeutic results were one of the most important nanotechnology applications produced over the last decade. This application's main objective is to improve medical efficacy while at the same time attaining lower toxicity levels[11]. Consequently, nanodrugs and nanodiagnostics have also been developed to improve the bioavailability profiles, allowing the delivery of lower doses and thus minimizing the adverse reactions seen in clinical settings of traditional medications and increasing the quality of patient health. Table 1 summarized few drugs using nanocarriers and their administration route[1].

Table 1: Some drugs using nanocarriers and their administration routes

Compounds	Nanocarrier	Application
DNA (gene therapy)	Solid lipid nanoparticles	Systemic
Cancer vaccine	Immunostimulatory acid-degradable microparticles	Subcutaneously
Camptothecin	Polymeric nanoparticles	Systemic
Tamoxifen citrate	Solid lipid nanoparticles	Systemic
Pilocarpine hydrochloride	Polymeric nanoparticles	Systemic
Clotrimazole	Solid lipid nanoparticles and nanostructured lipid carriers	Topical
Clozapine	Solid lipid nanoparticles	Systemic
Coenzyme Q 10	Solid lipid nanoparticles	Topical
Titanium dioxide	Solid lipid nanoparticles	Topical
5-Fluorouracil	Nanostructured lipid carriers	Systemic
Ibuprofen	Solid lipid nanoparticles	Topical
Insulin	Solid lipid nanoparticles	Systemic
Isotretinoin	Solid lipid nanoparticles	Systemic
Ketoconazole	Solid lipid nanoparticles	Topical
Mifepristone	Solid lipid nanoparticles	Systemic
Retinoids	Solid lipid nanoparticles	Topical
Triptolide	Solid lipid nanoparticles	Systemic
Vitamin A	Solid lipid nanoparticles	Topical
Etoposide	Nanostructured lipid carriers	Systemic
Docetaxel	Nanostructured lipid carriers	Systemic
Paclitaxel	Nanostructured lipid carriers	Orally

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1.3. **Regenerative Medicine**

In order to improve, repair or replace organ/tissue function, tissue engineering puts together ideas and technologies from engineering and life sciences. The traditional definition of integrating cell, scaffold (artificial extracellular matrix) and the bioreactor technology in design and manufacture of organs/neo-tissues has regulated this multidisciplinary area since its inception. Each tissue or organ in human body consists of mesenchymal cells (supporting cells) and parenchymal cells (functional cells) embedded in extracellular matrix to form the microenvironment, and these microenvironments forms organs and tissues of human collectively[12]. Human body is the "bioreactor" in terms of developing and preserving organs and tissues, exposing the cell's microenvironment and the extracellular matrix to biochemical signaling and biomechanical processes.

Nanotechnology has the ability to provide tools that can speed up advancement in organ engineering. To accomplish the more optimistic regenerative medicine goals includes control over cell's fundamental nanostructures and the extracellular matrix. Cells, usually microns in diameter, are made up of various nanosized components all of which work together to make the highly organized, self-regulating unit[3], [11], [12]. Cell-based therapies have created tremendous interest in the media and medical community, particularly those based on stem cells, and are one of the most innovative and active fields of research in regenerative medicine. The speed of work could be increased by developing multifunctional instruments to facilitate cell activity control and alteration[12]. Although nanomedicine focuses primarily on the cancer-related research, there is significant scope for application of nanotechnology in cell-based regenerative medicine therapies, e.g. in localization, recruiting and marking of stem cells to initiate the regeneration process.

II. CONCLUSIONS

Nanotechnology is a new interdisciplinary field incorporating biology, chemistry and chemical engineering. It is expected to bring to significant progress in individualized medicine, improving the specificity and sensitivity of current methods for finding and identifying the biomarkers and developing new nanodiagnostic devices. This would allow for faster and more tailored diagnosis and intervention, increase drug treatment efficacy and reduce side effects. In the last decades, it is participated in the implementation of several nanomedicine technologies in clinical practice, from the medical devices to nanopharmaceuticals. Nanomedicine is still in its early stages, and there are still many of its technologies in the research stage. The drug carriers mentioned were effective in vitro in nanopharmaceuticals but work still needed to be done in vivo. In practical applications tissue engineering and bone engineering have been effective in removing vital organs and bones. Nanomedicine is very exciting and its potential is rapidly evolving. The outcomes of the study are meant to help the less fortunate and pave the way for such a brighter future.

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