Nanotechnology: Application in Biology and Medicine

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Abstract

Nanotechnology is a novel and rapidly growing multidisciplinary field with major and multifold advances in the fields of engineering, electronics, energy, environment, biology, and medicine. The foundation of this novel science is laid down with the visionary ideas of Feynman in the 1950s. In this chapter the history of nanoscience is presented and an overview of applications of nanoparticles in biology and medicine are discussed. Several applications ranging from bioseparations, biosensing, molecular imaging, drug delivery, to hyperthermic treatment have been summarized.

Keywords

Nanotechnology · Nanoparticles · Applications · Biology · Field

1.1 Introduction

In higher animals and human beings, living process depends on interaction between cells and other smaller biomolecules that take place in nanoscale region. Organization of nanomaterials is central to biology and such intrinsic nanobiology has been noticed and investigated from the good old days. With the emerging tools and technologies in this field there is a lot of scope on the understanding of how biological systems work on the nanoscale and how these systems are integrated within the cells. Nanotechnology is a multidisciplinary field with a novel scientific approach and with a tremendous potentiality in traditional as well as advanced fields of biology, chemistry, physics, engineering, electronics, and medicine. The ultimate goal is to derive the engineering principles that govern the cellular functions, from

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D. B. Siddhardha et al. (eds.), *Model Organisms to Study Biological Activities and Toxicity of Nanoparticles*, https://doi.org/10.1007/978-981-15-1702-0_1

growth to apoptosis. Hence, nanotechnology enables novel ways and means to detect and measure biology both in vitro and in vivo.

1.2 History of Nanotechnology

Nanotechnology has its background throughout the human history. Humans were engaged in this technology, without having appropriate knowledge on it, and even without understanding the nature of these objects and processes. The use of kajal has been prevalent in South Asia, India, North Africa, and Middle East. Indian women prepared this cosmetic from the soot of lamp burning edible oil, by holding an earthen pot above the flame. This was collected and mixed with cow ghee and is ready to use. The carbon black thus obtained is of very fine size, i.e., is nano size and the application to the eye lids gives a cooling effect. One more example is the well-known invention of Indian ink that relies on producing carbon nanoparticles in water (known around 2700 BC). Faraday prepared colloidal gold in 1856 itself. Colloidal gold has been utilized in the preparation of glasses and vases to give them color. Also, Ayurveda, the Indian system of medicine, uses gold in several preparations. Colloidal gold is believed to be a remedy for chronic inflammations and several other diseases. Paracelsus treated human diseases by using gold and other inorganic compounds. Silver in the colloidal form is also considered to be a potent natural antibiotic, used in treating several diseases for thousands of years. However, the actual concept behind nanoscience began with a lecture by a Noble Laureate physicist named Richard Feynman on December 29th, 1959. His lecture titled "There is plenty of room at the bottom" gave scope to decrease the size of things, and tiny structures could be formed by arranging in the way we need. He was the first to propose that the materials at the nano range would present future opportunities. He believed in the existence of nanostructures in the biological systems. He even imagined the use of tiny machines in medicine. He further speculated the manufacturing of nanoscale machines. However, he never used the word nanotechnology. Though the practical ideas of Feynman were not implemented, his vision awakened the interest of many scientists and paved the way for this new field of research. The term nanotechnology was actually coined by a Japanese scientist named Noris Taniguchi in 1974. He proposed that nanotechnology consisted of processing, separation, consolidation, and deformation of materials by one atom or one molecule. Later with the invention of sophisticated instruments such as electron microscope and scanning tunneling microscope (STM) that could image and manipulate atoms, and Atomic force microscope (AFM) that structures on the atomic scale could be observed (Miyazaki and Islam 2007). Several series of events came into light and the main developments were summarized in the Table 1.1.

Nanoscience is basically the study of fundamental principles of molecules and structures with one dimension between 1 and 100 nanometer. These structures are known as nanostructures, and nanotechnology is the application of these structures into useful nanoscale devices. Today, nanotechnology is a vivid and vital area of

Table 1.1 Timeline events in Nanotechnology

Year	Developments in nanotechnology
2000 years back	Sulfide nanocrystals were used to dye hair by Greeks and romans
1000 years back	Gold nanoparticles of various sizes are used to create different colors on glass windows.
1959	First concept and vision of nanotechnology - R.Feynman
1974	Taniguchi coined the term nanotechnology
1981	Invention of scanning tunneling microscope.
1986	First book on nanotechnology "Engines of Creation"—Theory of molecular engineering became popular
1986	Invention of atomic force microscope.
1987	Development of magnetic force microscope.
1991	Discovery of carbon nanotubes S. Iijima.
2000	Launching of National Nanotechnology initiative
2002	Magnetic nanoparticles were used to report hyperthermic regression of tumors in mice.
2007	First human clinical trials for the treatment of cancer by hyperthermia by Dr. Johanssen and co-scientists.
2011	Molecular nanotechnology era began

research with tremendous prospects, changing the direction of science with a variety of applications in diverse fields, in all spheres of life.

1.3 Definition

Nanotechnology is defined by the National Nanotechnology Initiative as "Research and technology development at the atomic, molecular or macromolecular scale, leading to the controlled creation and use of structures, devices and systems with a length scale of 1–100 nanometers".

The definition given by European commission is "Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale".

1.4 Importance of Size

A billionth of a meter is a nanometer or nm. Nanometer was first used by Zsigmondy for specifying particle size. Nanotechnology deals with 0.1–100 nm. The lower edge of the nano world is defined by the size of single atom; diameters vary from 0.1 nm, a hydrogen atom, to about 0.4 nm, a uranium atom. This represents the smallest structure, as we cannot create building blocks smaller than atoms. The upper edge of the nano world is 100 nm. Because of the minute size and high

surface area-to-volume ratio, they display new physics and chemistry leading to a new behavior. A few examples are:

- Inert materials become catalysts—Platinum
- At room temperature solids turn into liquids—Gold
- Opaque systems are changed to transparent ones—copper
- Insulators turn into conductors—Silicon
- Stable materials turn combustible—Aluminum

These exceptional magnetic, electrical, thermal, and optical properties are due to their spatially confined electrons (Alivisatos 2004).

- The electrical properties depend on the diameter of the material. They have very high electrical conductivity, due to the fewer defects in the crystal
- The thermal conductivity is enhanced due to the heavy vibration of covalent bonds.

Thus the nanomaterials display unique optical, biological, electrical, mechanical, and magnetic properties that are summarized in Table 1.2.

Also this size range is intimately connected with the phenomena in the biological systems. The basic building blocks of life, including cells and biomolecules fall in this range. For instance, DNA molecule is only 5–10 nm. Nanoscale devices such as nanopores (~2 nm openings), inorganic nanowires (~10 nm diameter), and spherical nanoparticles (10–100 nm diameter) are of similar size as biological entities. Nanoparticles less than 20 nm can move through blood vessels. Also nanoparticles can enter into stomach epithelium and can cross the blood brain barrier (Vinogradov et al. 2004; Lockman et al. 2003; Russell-Jones 1999). Surface charge also plays a prominent role in the ability of nanoparticles to penetrate the blood brain barrier (Lockman et al. 2003). The size of nanoscale devices also makes them readily interact with biomolecules within the cell, without changing the behavior and biochemical properties of those molecules (Bogunia-Kubik and Sugisaka 2002).

These properties revolutionized researchers from different fields and paved the way for several promising and potential applications in the following fields.

- Engineering and transportation

Table 1.2 Size-dependent properties of nanoparticles

Property	Examples
Biological	Permeability through biological barriers is increased
Electrical	Electric resistance in metals is increased
Optical	Spectral shift of optical absorption and fluorescence properties
Magnetic	Magnetic property is increased—superparamagnetism
Catalytic	Greater catalytic efficiency because of high surface-to-volume ratio
Mechanical	Increased toughness and hardness of metals and alloys Superplasticity and ductility of ceramics

- Electronics and information technology
- Energy and environment
- Physical and biological sciences
- Agriculture and industry
- Medicine and health care

However, we will confine to the applications in biology and medicine in this chapter.

1.5 Applications in Biology and Medicine

As all the biological processes are balanced by the action of biological molecular nanomachines, nanotechnology is of prime significance in biology and medicine. Nanotechnology has opened up lightning advances in biology and medicine with novel and critical tools and applications, as biological systems are highly responsive and restorative. The mechanical and chemical properties could be characterized with the available novel nano tools. One outstanding development in these fields is optical nano-biosensors, to study the single living cell in a minimally invasive manner. By this method, protein function at the single cell level can be analyzed without disturbing the chemical makeup of the cells. Cellular processes such as, functioning of proteins that occur in subseconds time, in their natural environment can be quantitated. Also apoptosis, known as programmed cell death, a cellular process usually observed in normal and diseased, is significant to both biology and medicine. To study the pathway of apoptosis, the proapoptic members, cytochrome c, caspase-7, and caspase-9, have to be detected. The in vivo detection and identification of these can be done by using optical bio-nanosensors.

The applications in biology and medicine are summarized separately.

1.6 Applications in Biology

As biological species exhibit molecular structures at the nanoscale levels, nanotechnology plays prominent role biology. Understanding the biological processes at the nanoscale level is the driving force behind the development of nanotechnology (Whitesides 2003). Nanoparticles with distinct size, shape, and surface chemistry can be engineered in a wide variety of biological applications. Thus nanoscale structures such as nanopores, nanofibers, nanowires, nanotubes, nanochannels, and nanocapacitors are investigated in many biological applications such as molecular imaging, biological separation, biosensing, bacterial detection, and sequestration as detailed below:

1.6.1 Bioseparation: Separation and Purification of Biological Molecules

Bioseparation is the separation and purification of certain biomolecules selectively from a complex mixture. In biological research, selective and efficient isolation and purification of specific cells from complex mixture is the need of the hour. The traditional methods of separation such as precipitation, filtration, centrifugation, and chromatography are time-consuming. Also they suffer from several drawbacks. To overcome the drawbacks in the traditional techniques, nanomaterials can be utilized. Thus nanotechnology offers promising applications by designing novel nanobiological objects in the bioprocessing that can be utilized in bioseparation, imaging, and sensing of several different biological compounds (Wang and Wang 2014). It plays an important role in different biological processes and in the industrial production of biological compounds.

1.6.1.1 Separation of DNA

DNA molecules are negatively charged in physiological media, whereas in acidic media they acquire positive charge due to the phosphate group's protonation. Salmon sperm was separated by means of electrostatic interactions, using magnetic mesoporous silica-magnetite nanocomposites prepared by the template-assisted method (Melzak et al. 1996). At the physiological pH, the nanocomposites acquired a positive charge that facilitated electrostatic interactions with the negatively charged phosphate backbones of DNA, paving the way for efficient separation.

1.6.1.2 Separation of Proteins

Proteins play a crucial role in cell machinery and structure. Previously, conventional protocols such as ultra-filtration, precipitation, and chromatography were of paramount importance in the separation and purification of proteins and peptides. The alternate method is the magnetic separation of specific proteins by utilizing magnetic nanoparticles (MNPs). Magnetic nanoparticles bind to different copolymers of protein by various mechanisms such as ligand binding, vanderwalls, hydrophobic, and electrostatic interactions (Churchill et al. 2004; Tenzer et al. 2013) .This can be done in samples such as blood, plasma, urine, cell lysate, or any biological fluid. The sample is mixed with MNPs with hydrophobic ligands or ion exchange groups and incubated for an appropriate period, so as to allow the affinity species to bind to the ligands anchored to the MNPs. The proteins are now separated by magnetic decantation. By using proper procedures of elution, the purified target proteins are recovered by displacement from the MNPs. When compared with conventional methods, protein separation using MNPs is advantageous for the following reasons.

(a) Sample preparation is easy and less time-consuming
(b) Purification process is simple, easy, and rapid

Table 1.3 MNPs in the separation of different biomolecules

Biomolecule	Core	Functionalization	Interaction type	Reference
Trypsin	Fe_3O_4	Carboxylic acid group	Affinity	Khng et al. (1998)
Lysozyme	Fe_3O_4/silica	Polyacrylic acid	Electrostatic	Shao et al. (2009)
BSA	Silica-coated MNPs	Alkyl chains	Hydrophobic	Chang et al. (2010)
SH-SY5Y cell	Fe_3O_4	PAA PEI	Electrostatic	Calatayud et al. (2014)
Streptavidin Protein	Silica NPs(2 nm)	Multiple layers of Fe_3O_4 Extra layers of silica Biotin	Affinity	Kyeong et al. (2015)
$CD3^+$cells from spleen	Fe_3O_4	Anti-CD3 monoclonal antibody	Affinity	Cui et al. (2011)
Salmon sperm DNA	Fe_3O_4	Mesoporus silica	Electrostatic	Melzak et al. (1996)

(c) Magnetic separation does not need equipment such as chromatographic systems or centrifuges.
(d) Small amounts are sufficient for the separation process
(e) Method is cheap and scalable

1.6.1.3 Separation of Biomolecules

MNPs are utilized in separating several biomolecules, owing to their versatility of functional groups that can be used to modify their surface (Earhart et al. 2014; Zhang et al. 2013; Intorasoot et al. 2009). T-cells from the spleen were successfully separated utilizing Anti-CD 3 monoclonal antibody bioconjugated to core/shell Fe3O4/Au MNPs (Cui et al. 2011). Some more research findings are tabulated in Table 1.3.

1.6.2 Probing of DNA Structure

In biotechnology assays structural polymorphism in DNA serves as a biological signal. Quantum dots, the semi-conductor nanoparticles, with all the three dimensions in the nano range are receiving recognition for their biological applications. These photoluminescent nanomaterials are being developed both as sensors and dyes to detect different intrinsic DNA structures (Mahtab and Murphy 2005).

1.6.3 Fluorescent Biological Labels

In the biological world, fluorescence is a commonly and widely used tool. In biological staining and diagnostics, semiconductor nanocrystals were used as fluorescent probes. In ultrasensitive biological detection, zinc sulphide-capped cadmium selenide quantum dots are coupled covalently to biomolecules. When compared with the conventional organic dyes such as rhodamine, these are brighter and have tunable, narrow symmetric emission spectrum. These features allow them to be used as a direct probe or sensitizers.

1.6.4 Biological Processes

Nanoparticles are vital tools to study and characterize biological processes. Several novel and exciting applications include the following.

- Improvement of current techniques in cellular and molecular research
- Activation of cell signaling pathways
- Regulation of protein production
- In the molecular dynamics, individual molecules in live cells can be visualized.
- Insight into molecular processes and cell functions involving complex signaling pathways

Cho et al. 2012 demonstrated that the cell signaling pathway can be controlled by using functionalized magnetic nanoparticles. When the magnetic field is applied, an apoptosis signaling pathway is promoted, which is demonstrated in vivo in zebra fish. Likewise, several such methods of noninvasive nature provide a promising tool for basic biological research.

1.6.5 Biosensing with Magnetic Nanoswitches

Weissleder along with his co-scientists was the first to propose magnetic relaxation of nanoswitches. Pathogens, proteins, DNA, and biological processes such as enzymatic function can be accurately detected using the new biosensors (Perez et al. 2002; Koh et al. 2008; Taktak et al. 2007). For the quick and quantitative analysis of unprocessed biological samples, a chip-based diagnostic magnetic resonance (DMR) system was developed (Lee et al. 2008). When compared with the conventional methods miniaturized DMR has the following advantages.

(a) DMR micro system can be prepared as disposable units.
(b) Minimum amount of sample is sufficient (micro liters)
(c) Quick screening of analytes, can be performed
(d) High detection sensitivity
(e) Screening can be performed even in opaque media

1.6.6 Single Cell Phenotypes

Single-cell phenotypes can be directly measured by using nanostructures. The mass of adherent cells were measured using resonating sensors (Park et al. 2010). In the cell cycle, at certain check points growth rates varied.

1.6.7 Delivery Vehicles

Nanoparticles serve in delivering various agents. A few of them are mentioned below.

1.6.7.1 Delivering Hydrophobic Compounds Without Solvents

Most biologically active compounds are poorly soluble in water. One traditional approach is using dimethyl sulfoxide (DMSO) as a solvent. But DMSO cannot be used for in vivo applications. Also all compounds cannot be solubilized in this solvent. To overcome these problems in delivering the hydrophobic compounds polymeric nanoparticles that possess hydrophobic cores are used. The advantages of using these particles include.

(a) The solubility of active agent is increased
(b) Safeguards the agent from the environment until it is released from the nanoparticles

1.6.7.2 Delivering siRNA for Biological Studies

In cell culture the gene functions can be studied by using siRNA. However, there are many biological obstacles in the delivery of siRNA such as difficulty in entering the cell due to its high molecular weight and negative charges, degradation by nucleases within the cell, rapid clearance, and instability in vivo (Nie and Emory 1997; Peng et al. 2009; Liu et al. 2008). Nanoparticles are a good alternative to overcome these obstacles.

1.6.7.3 Delivering Agents to Subcellular Organelles

Delivering agents to subcellular organelles throws light on certain molecular processes that are not known in the organelles. Nanoparticles are used as carriers to deliver agents to subcellular organelles as they can be easily modified. Tools for subcellular targeted delivery to the nucleus (Pouton et al. 2007) cytosol (Vasir and Labhasetwar 2007), mitochondria (Yamada and Harashima 2008), lysosomes (Lloyd 2000), and endosomes (Bareford and Swaan 2007) have been developed.

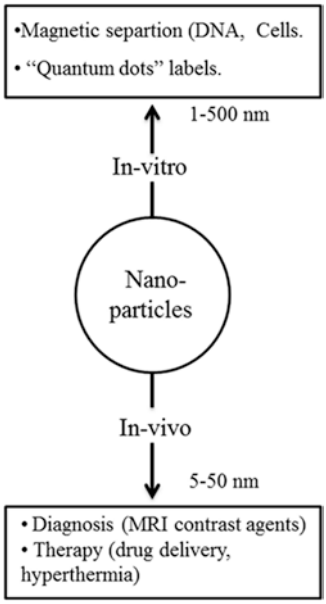

Fig. 1.1 Nanoparticles utilized in medicine

1.7 Applications in Medicine

One of the key roles of nanotechnology is for the advancement of health and medicine. This technology offers promising and potential developments in pharmaceuticals, disease diagnosis, target specific drug delivery, cancer treatment, medical imaging, tissue regeneration, implantable materials, and tissue regeneration. Nanoparticles are used to diagnose proteins and DNA, as probes for in vivo investigations of cell functions, as carriers of drugs in drug delivery system (Alivisatos 2004) for magnetic cell separations, and as contrasting agents in magnetic resonance imaging (MRI). For many applications the size of nanomaterial is very crucial (Fig. 1.1). The various applications in medicine are detailed in Fig. 1.1

1.7.1 Drug Delivery

Nanoparticles are used for new formulation of drugs and also for site-specific delivery. In this technology, the active agent of the drug is deposited in the pathological site only. Hence it reduces the drug consumption, lowers the side effects and is also cost-effective. Drugs are encapsulated in nanoshells, polymer capsules, organic dendrimers, and micelles. Also many drugs that cannot be given orally because of their lower bioavailability can be benefited by this technology (El-Shabouri 2002; Hu et al. 2004).

1.7.2 Diagnostic Applications

Detecting diseases at an early stage with greater efficiency and economy is the need of the hour. Traditional diagnostic methods depend upon the manifestation of visible symptoms. Several nanoparticles such as quantum dots, gold nanoparticles, and magnetic nanoparticles have been utilized in diagnostics.

1.7.2.1 Quantum Dots

All the three dimensions are in nano range in a quantum dot. These exhibit broad excitation spectra, high sensitivity, and stable fluorescence. Also they do not need lasers. Their infra-red colors enable whole blood assays. Visualization of cancer cells is possible with luminescent quantum dots. Intracellular imaging can be performed by labeling of target molecules with quantum dots. Thus these have several applications in genotyping, molecular diagnostics, and biological assays.

1.7.2.2 Gold Nanoparticles

Among the metal nanoparticles, gold nanoparticles are the most stable (Stroscio and Dutta 2003). Colloid gold has been used as biosensors, in disease diagnosis, and in gene expression. Gold nanoparticles are extensively used as sensors because of their surface chemistry. The gold nanoparticle-based biosensors are employed in the detection of DNA or RNA targets with single nucleotide polymorphism at a detection limit of about 50 fM (Nam 2003).

Mirkin group has developed the bio-barcode method for protein and DNA (Hill and Mirkin 2006) target detection. Also this method has been reported for a biomarker for Alzheimer's disease (Georganopoulou et al. 2005). Prostate cancer can be detected by this method, by identifying prostate-specific antigen, a common cancer biomarker. PSA gold nanoprobes are generated by conjugating DNA

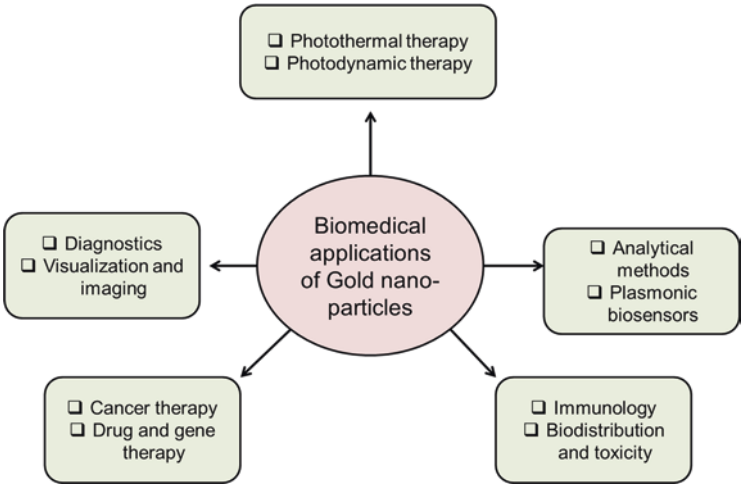

Fig. 1.2 Biomedical applications of gold nanoparticles

functionalized gold nanoparticles (30 nm) to PSA-specific antibodies (Swierczewska et al. 2012). The bio-barcodes are the DNA strands. Several antitumor substances such as paclitaxel, cisplatin, doxorubicin, and oxaliplatin were conjugated with gold nanoparticles. The biomedical applications of gold nanoparticles are depicted in Fig. 1.2.

1.7.3 Cardiac Therapy

Nano particles are widely used in cardiovascular therapy at the cellular level and play a promising role in treating cardiovascular diseases. These methods can be utilized in diagnosis, imaging and tissue engineering (Lanza et al. 2006). Miniaturized nanoscale sensors—quantum dots, nanobarcodes, and nanocrystals—can sense and monitor complex immune signals. Also critical cardiovascular diseases can be treated by the newly designed nanomachines.

1.7.4 Orthopedic Applications

Nanomaterials, nanofibers, nanotubes, nanopolymers, and ceramic nanocomposites can be utilized for the depositing of minerals containing calcium on implants. Thus nanostructures play a prominent role in improving the attachment of implant to the surrounding bone by enhancing bone cell interactions and thus improve the implant efficacy.

1.7.5 Dentistry

The role of nanotechnology in the field of dental care (West and Halas 2000; Shi et al. 1999) will ensure better oral health. Covalently bound artificial materials such as sapphire may replace the upper enamel layer to increase the durability and appearance of teeth. Thus in the maintenance of natural tooth, nanodentistry is of considerable significance (Shellhart and Oesterle 1999).

1.7.6 Magnetic Resonance Imaging (MRI)

Healthy and pathological tissues can be distinguished by using MRI, as this shows a clear contrast of the image between these two tissues. These images can be improved by adding “contrasting agents, such as gadolinium (Gd) chelates which are nonspecific and allow only a short time imaging window (Kubaska et al. 2001; Low 2001). Colloidal iron oxides, the first liver specific contrast agents, play a crucial role as MRI contrast agents (Halavaara et al. 2002).

A new contrast agent for MRI in cancer imaging was developed by (Yu et al. 2008). Interestingly this agent can deliver anticancer drugs specifically to tumors, beneficial in both cancer imaging and therapy (Yu et al. 2008).

1.7.7 Cancer Therapy

Baker and his coscientists were the first to demonstrate the delivery of therapeutics to cancer cells in vitro and in vivo. The size range used for in vivo applications ranges from 2 to 150 nm. Large particles with diameter of 300 nm are used as MRI contrast agents of gastrointestinal tract.. Large magnetite nanoparticles (40–150 nm) are suitable for imaging spleen and liver. Small nanoparticles (20–40 nm) are used to visualize tumors, whereas ultra-small, less than 20 nm, superparamagnetic iron particles are utilized for myocardial ischemic diseases and for imaging vessels in angiography.

In cancer treatment carbon nanotubes serve as a diagnostic and therapeutic tool. Cisplatin is widely used as an anticancer drug. But it is highly toxic and requires specific delivery. Scientists synthesized ultra-short carbon tubes for the delivery of cisplatin that could avoid the reticuloendothelial system.

The first clinical trial using nanoparticles for anticancer drug delivery was performed in the 1980s. From then onwards several new nanoparticles have been approved and many are under development.

The various nanosystems utilized in treating cancer are summarized as:

Nano shells—utilized in deep tissue thermal ablation and in tumor specific imaging

Nano wires—utilized in detecting DNA mutation and disease protein biomarkers

Nanocrystals: 2–9.5 nm in size

- To improve the formulation for poorly soluble drugs.
- For labeling of breast cancer marker HeR2

Nanoparticles: 10–1000 nm in size

- Utilized in MRI and as ultrasound image contrast agents.
- For targeted drug delivery
- As reporters of apoptosis and angiogenesis

Carbon nanotubes: 0.5–3 nm in diameter and 20–1000 nm length
Utilized in the detecting DNA mutation
Utilized in the identification of disease protein biomarker.

Quantum dots: 2–9.5 nm in size, helps in optical detection.

Gene Therapy

The creation of novel adenoviral vectors has revolutionized cancer gene therapy. Barker and Berk in 1987 created an oncolytic adenovirus dl1520, which has been utilized in specific targeting of tumor cells.

1.7.8 Hyperthermia

The primary goal in cancer therapy is the selective killing of cancer cells without disturbing normal cells. The use of nanomaterials in heat therapy, known as Nanoparticle Hyperthermia involves applying heat to tumor cells (Abenojar et al. 2016). The heating power of the particles is quantified as the specific absorption rate (SAR), which describes the amount of energy converted into heat per time and mass (Moroz et al. 2002). Recent studies proved that large tumors can be heated without any problem with a proper regulation of the magnetic mass used and the intra tumoral particle distribution.

Pathogen Detection and Isolation
For detecting and isolating pathogens various nanoparticles has been explored as sensors. The magnetic and optical property of the nanoparticles has been utilized. Magnetic biosensors have widely been utilized for detecting pathogenic bacteria. Magnetic nanoparticles are coated with antibodies against surface antigens (Varshney and Li 2007; Xia et al. 2006). Researchers devised a method without antibodies to detect single gene mutations. This could detect drug-resistant strains of *Mycobacterium tuberculosum* in less than 3 h from sputum samples. In the conventional system, identifying this bacteria takes long time as this bacteria grows slowly in the culture medium.

By utilizing both metallic nanoparticles and quantum dots, optical biosensing of bacteria has been possible. Many targets can be detected simultaneously by the bio-barcode assay. *Bacillus subtilis* was detected at 2.5 fM concentration (Hill et al. 2007) by this method. Also, *Salmonella enteritidis* was detected at 0.2 fM (Zhang et al. 2009). Quantum dots are also used as pathogen sensors.

1.7.9 Ophthalmology

A number of applications are available in the field of ophthalmology also. A novel nanoscale-dispersed eye ointment (NDEO) for treating evaporative dry eye has been successfully developed by Zhang et al. 2014. Some more applications are as follows:

- Scars can be prevented after glaucoma surgery
- Oxidative stress treatment
- Retinal degenerative disease can be cured using gene therapy
- Measurement of intraocular pressure

1.7.10 Tissue Engineering

Nanoscale biomaterials are utilized as carriers for artificial matrices for tissue engineering. However, the scaffold should mimic the structure and biological function

of the native extra cellular matrix not only in the physical structure but also in chemical composition. Nanotechnology can be used to create nanofiber and nanopatterns for mimicking native tissues (Chung et al. 2007). Tissue engineering is now feasible through nanotechnology and is used in stem cell tissue engineering, neural cell tissue engineering, cartilage cell tissue engineering, bone and hepatic cell engineering.

1.8 Conclusion

Nanotechnology, a multidisciplinary science with multidirectional development will provide opportunities for developing new methods, materials, and devices for more innovative applications. Nanomaterials with distinct biological properties, due to enhanced surface area and nanoscale effects, significantly affect their interaction with biomolecules and cells, creating an excellent approach for characterizing basic biological processes. Such studies can provide novel and critical insights into cellular functions and molecular processes. Also integration of proteomics and genomics with nanotechnology will throw more light in understanding biological processes.

Also, in the field of medical sciences, nanotechnology has brought a revolutionary change in diagnostics, therapy, and drug discovery. There is an immense scope and possibility to design and develop multifunctional targeted nanoparticles to diagnose and treat dreadful diseases such as cancer. Also early detection of disease, simple and inexpensive tests, sophisticated imaging methods, minimal invasive treatment, and several endless lists of potential benefits will change the medical field in future.

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