2 Biomedical Applications of Nanoparticles

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Abstract

During the last decade, biomedical applications of nanoparticles describes the most interesting and investigated applications of nanoparticles, emphasising their therapeutic impact. There have been enormous developments in utilising the power of nanotechnology in various fields including biomedical sciences. The most important biomedical applications of nanoparticles are in disease diagnosis and treatment. Functionalised nanoparticles possess unique properties as contrast agents for dual and even triple modal imaging. The potential of these new generation nanoparticles in targeted drug delivery has revolutionised safe and effective pharmacotherapies for complex diseases. One more step ahead, theranostic nanoparticles are equipped with dual capabilities for disease diagnosis as well as treatment. Specifically, designed nanoparticles have also been utilised to improve the delivery and efficiency of different vaccines, including their application in cancer immunotherapy. This chapter provides an overview of the biomedical applications of nanoparticles and recent advancements in this area on the basis of current research. Progress made in the therapy of severe diseases, such as cancer and difficult infections, is strictly correlated to the scientific progress and technological development in the field of materials science. Nanoparticles have numerous therapeutic applications, starting with the design of new drugs, delivery systems, therapeutic materials, and their contribution to the development of preventive strategies. The chapter highlights the impact of nanoparticles on the therapy of infections, antimicrobial effect, and also anticancer strategies. Nanoparticles are minute particles that produce a major change in the healthcare and biomedical industry. It is not restricted to any field and its presence is observed in every field of biomedicine from diagnosis to treatment to implants to cosmetics.

Keywords

Molecular biology · Biochemistry · Drug targeting · Diagnosis · Cell biology · Biological engineering

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1 Introduction

'Nano', when used as prefix to anything, is 'one billionth' fraction, or 10^{-9} of something'. The concept was first described by physicist and Nobel laureate Richard Feynman in his lecture at American Physical Society on December 1959. The lecture was entitled 'There's plenty of room at the bottom'. Over the years, there have been many revolutionary developments across various fields that have supported Feynman's ideas of modifying matter at the atomic scale (Bonelmekki 2017). The research has been continued all these years and will continue for many years to come. The combination of nanotechnology and biotechnology is referred to as nanobiotechnology (Saji et al. 2010). When applied these concepts to improve the medicinal and healthcare of society, it is referred to as biomedicine.

Biomedicine is a branch of medical science that applies biological and physiological principles to clinical practice (Quirke and Gaudillière 2008). It is not restricted within the boundaries of a specific field, but is an amalgamation of numerous fields that are directly or indirectly associated with humans and human health. Some of them are (Wade and Halligan 2004; Engel 1977):

- Molecular biology
- Biochemistry
- Biotechnology
- Biological engineering
- Cell biology
- Cytogenetics, bioinformatics, and gene therapy
- Embryology
- Microbiology, virology, and immunology
- Neuroscience
- Pathology and toxicology, etc.

Nanobiotechnology has proved to be an interesting resource, for revolutionising these biomedical fields in the twenty-first century. It has changed the concept of health. The development in nanobiotechnology has opened the doors for developing newer and modified nanoparticles that shares a property different from its parent compound. This review will highlight the major applications and use of nanoparticles in recent history and its future that will help to improve the biomedical and healthcare system across the globe.

1.1 Applications of Nanoparticles in Biomedical

I. **Molecular Biology**

As per Oxford, molecular biology can be defined as 'the branch of biology that deals with the structure and function of the macromolecules (e.g. proteins and nucleic acids) essential to life'.

1. **Nanoparticles for cell detection and separation:** Outcome of research depends on selection and quality of raw materials and interpretation of data. In molecular biology, it is very important to isolate specified cells from the mixture or group of cells. Based on the efficiency of isolation of a selected cell from complicated mixtures affects the biological research and limits its role for biological applications. Nanoparticle acts as a sensitive tool not only for detection of cells in mixture but also can be used for isolation of those cells. Besides, it is more selective and can be used to detect cells found in trace amounts. This detection of circulating tumour cells (CTCs) is also possible by this technique. It has also been used to successfully capture those circulating tumour cells. Hence, CTCs can be the necessary aid for deeper understanding of the biology of cancer metastasis. It is observed that it acts as a prognostic biomarker for overall survival in cancer patients having metastatic breast, colorectal, and prostate cancer (Wang and Wang 2004).
2. **Nanoparticles for analyte detection:** Detection of biological analyte such as DNA, RNA, and proteins is a tedious and difficult task. Nanoparticle is help-

ful for both qualitative and quantitative analysis of these compounds. Besides, it has a very high level of sensitivity for the same. The advantage of using nanoparticles is that they have a very large surface-area-to-mass ratio, are small in size, and can be modified for study of composition-dependent properties that use surface ligands to detect efficiently and more rapidly.

Mirkin group has successfully developed gold nanoparticles for signal transduction amplification. It uses unique surface chemistry of gold nanoparticles which acts as the bio-barcode that detects protein and DNA targets (Wang and Wang 2004).

3. **Subcellular targeting:** Nanoparticles is not only restricted to deliver drugs at cellular levels, but it can also be used for delivering agents to subcellular organelles, which can enlighten us about various molecular processes and pathways that are still unknown. Modern tools for more effective subcellular targeting are being developed for targeted delivery to the cellular organelles such as nucleus, cytosol, endosomes, mitochondria, and lysosomes (Wang and Wang 2004).

II. **Biochemistry**

1. **As catalyst:** Use of substance to increase the rate of reaction without changing its chemical structure is known as catalysis, and use of nanoparticles in catalysis is one of the most widely used applications of nanoparticles. Of them, use of noble metal nanoparticles acts the best, because they have a very high catalytic activity for a large number of chemical reactions. They have a very large surface-area-to-mass ratio, which is responsible for its higher catalytic activity, and so they readily increase the kinetics of reaction. The major advantage of such catalyst is it has been used for development of sensors for rapid detection and they are being used for detection of diseases, moisture, impurities, etc. The most interesting example of such sensor includes glucose nanosensors for detection of diabetes. Other such sensors include choline nanosensors, nicotinamide adenine dinucleotide nanosensors, lactate nanosensors, triglyceride nanosensors, ochratoxin A detectors, urea nanosensors, C-reactive protein detectors, etc. (El Ansary and Faddah 2010).

   Similarly, it has been reported that Co_3O_4 is humidity sensitive in the visible wavelength region at room temperature, and so it can be used to detect the maintenance of temperature and humidity levels in air-controlled region (Sun 2006).

2. **Engineered nanoparticles:** Major advantage of nanoparticles is that their properties can be predefined, and based on our requirement, they can be selected. This has led to an attempt to form large varieties of nanoparticles and they are known as engineered nanoparticles. The high production, intense use, and quick disposal of engineered nanoparticles offers interesting developments in biomedical industry. Use of engineered nanoparticles in plant modification and for artificial photosynthesis to improve the yield is already under progress. Development of new metal in nanoparticulate form has been essential to improvise the yield and development of modified crops which can withstand extreme and uncontrolled environment. It has also been helpful to provide essential nutrients to plants required for their growth, improving the quality of crops without degrading the quality of soil (Rico and Chemistry 2015).

III. **Pharmacy**

1. **Drug Targeting** (Fakruddin et al. 2012)**:** Physiology and anatomy of diseased cells differ from normal cells. Drug targeting is possible by utilising these distinct features of diseased tissues. The pathophysiological conditions and anatomical changes of diseased or inflamed tissues can be triggered which offers a great scope for the development of nanoparticles that targets only diseased cells. This helps to increase the concentration of drug in diseased cells compared to normal dose. For example, nanosystems have better transmission and higher retention in tumour cells due to higher vascular permeability and impaired lymphatic drainage in tumours cells. Nanosystems are also quite selective for localised actions in inflamed tissues.

   Nanoparticles can effectively cross blood–brain barrier (meninges) and so can be used for brain targeting and CNS drug delivery. Drug loaded nanoparticles are more selective thereby improving drug efficacy and reducing drug toxicity.

   Nanosystems can also improvise the pharmacokinetics and pharmacodynamics of drug. It is used to mould the final properties of drugs as per the requirement of dosage form. This helps to reduce dose size and frequency, altering the side effects and maintaining the therapeutic efficacy of drug for longer duration within the required therapeutic window.

2. **Diagnosis**

   Current diagnostic methods for most diseases are efficient to identify only after symptoms are visible to medical professionals. Due to this, patient suffers from specific illness for longer time because symptoms appear only after a lag phase. Also, treatment may prove to be lesser effective by the time symptoms have actually appeared. The faster a disease can be detected, the better and more readily it can be cured. Besides, certain life-threatening diseases and disorders can be avoided or minimised by proper understanding of human body and its mechanism. Optimally, diseases should be diagnosed and cured before symptoms even manifest themselves (Fakruddin et al. 2012). This is only possible by improvising the sensitivity and speed of diagnosis.

   Vancomycin, when linked with iron and platinum nanoparticles (also known as FePt-vancomycin nanoparticles), exhibits more selective binding to Gram-negative bacteria at a concentration as low as 15 Cfu per mL. In comparison with luminescence-based assays for bacteria detection (detection limit: 180 cfu mL–1), FePt nanoparticles can detect ten times lower fractions (Sun 2006). Other diagnostics detection of pathogens and diseases/diseased cells includes nucleic acid diagnostics that allows diagnosis at an early symptomless stage of disease progression. This will help for a better and more efficient treatment. Polymerase chain reaction (PCR) and nanotechnology, when combined together, will expand the current options and ensure greater sensitivity and far better efficiency with lower costs. Besides, genetic disorders will be easily identified and cured more readily (Fakruddin et al. 2012). This has been discussed in detail in later part of this review.

   Mesoporous silica nanomaterials can also be used for diagnosis and drug targeting as it offers more loading and faster release of large quantities of biomedical agents (Saji et al. 2010)

3. **Rate-Controlled Drug Delivery** (Chan et al. 2009)

   Use of nanoparticles for controlling the dose, minimising it, and optimising the rate of release of drug, thereby maintaining the therapeutic dose in the body for longer period of time, helps to improve the efficacy of drug. It is more patient compliant and reduces adverse effects. Several dosage forms in the past and all the present dosages are being designed and developed with the similar intention. Doxil (doxorubicin entrapped in liposomes) was the first FDA-approved liposomal nanodrug formulation in 1995. It is used for the treatment of AIDS associated with Kaposi's sarcoma. It is one such example that has been used in modern day's therapeutics due to its improved activity and is quite successful.

4. **Photoablation Therapy** (Wu et al. 2015)
   A strategy involving the generation of heat by various nanoparticles using outsource energy for treating tumours and cancer has been reported and tested. Such model has been used for treating ovarian cancer and is more effective compared to normal chemotherapies due to reduction in adverse effects. Use of gold nanoparticles to enhance the temperature at targeting sites and destroying the tumour cells gave better and faster results due to their higher conductive properties. Besides, gold nanoparticles readily reach the targeted site and provide a non-invasive route of therapy.
5. **Other Therapeutic Application**

   (a) **Intracellular targeting**: Certain antibiotics fail to diffuse across the cell's lysosomal membrane. This is generally due to the ionic character of antibiotics and neutral extracellular membrane. Lysosomal pH is also responsible for this barrier. This created a need of a drug with greater and better intracellular efficacy which led to development of endocytosable drug carriers such as nanoparticles. Such nanoparticles have higher efficacy. For example, polyhexylcyanoacrylate ampicillin (PIHCA) was effective at a 0.8 mg dose and was more effective in mice compared to 32 mg dose three times a day.

   (b) **Chemotherapy:** Drug entrapped or absorbed in polyalkylcyanoacrylate nanoparticles are more effective in chemotherapy compared to those drugs which are delivered through conventional route. Besides, they have reduced adverse reactions due to lower dose. So far, mitoxantrone in polybutylcyanoacrylate, aclacinomycin in polyisobutylcyanoacrylate, granulocyte colony-stimulating factor in polyalkylcyanoacrylate, acyclovir in polybutylcyanoacrylate, and doxorubicin in polyalkylcyanoacrylate have been tested and passed for their better efficacy.

   (c) **Per oral administration of proteins and peptides:** Proteins and peptides readily undergo proteolytic degradation and, hence, have shorter biological half-life. They have poor absorption due to lack of its ability to cross biological membranes. However, formation of nanoparticles and nanocapsules has helped for successful delivery of enzymes and hormones such as insulin and growth hormone releasing factor.

   (d) **Ocular drug delivery:** Ocular drug delivery is quite problematic due to numerous reasons such as lachrymal drainage, shorter residence time (1–3 min), irritability, sensitive region, sterility, etc. However, this problem has been solved to a certain extent using nanoparticles having biodegradable characteristics. Polymers used for such delivery include albumin, polyester, and polyalkylcyanoacrylate. These polymers act isotonic to eye, are less irritating, and increase tissue adhesion and residence time of drug.

6. **Other Pharmaceutical Applications** (Fakruddin et al. 2012): It involves drug delivery and gene delivery using liposomes, niosomes, solid liquid nanoparticles, etc. This has been done to modify the properties of molecules and has been quite successful for cardiac therapy, CNS drug delivery, dental care, ophthalmic treatments, orthopaedic applications, etc.

IV. **Cell Biology** (Thimiri Govinda Raj and Khan 2016)
Cell biology revolves around the study of cells and cellular structures. Isolation of cells and cell organelles play an important role for studying the unique features in such a minute structure. For such studies, organelle fractionation plays a major role. The governing factor for organelle fractionation is high yield and high purity. Density-gradient centrifugation (sucrose-based fractionation) is the method generally used for fractionation. This method is based on principle of difference in density for separation. It is further modified based on equilibrium or nonequilibrium centrifugation for organelle separation. Other method used for fractionation involves antibody-based pulldown assay. This assay makes use of magnetic beads that are tagged with antibodies selectively targeting the subcellular compartments. For example, TOM22 antibodies conjugated with magnetic beads are used for isolation of mitochondria. This principle is further modified by post-nanoparticle labelling-based fractionation. Here, organelle-specific antibody conjugated nanoparticles are used to target fractionated subcellular compartment. Such methods improve the yield, purity, and rate of fractionation. Selection of nanoparticles and its designing is based on the cells and cell organelles that are to be isolated.

V. **Embryology** (Remião et al. 2018)
Infertility and subfertility, defined as difficulty to conceive, is a condition that has affected people worldwide. The most revolutionary treatment in this area is assisted reproductive technology (ART) comprising of in vitro embryo production. Nanotechnology can be very useful in the development of non-invasive detection, diagnosis, and minimally invasive treatment of infertility-related disorders. Besides, it also prevents multiple fertilisation which has been a major challenge in current therapy. Also, the use of biosensors mentioned above helps to diagnose faster and more accurately. Gold, silver, carbon, and magnetic nanomaterials are the main materials used to develop new methods of genetic diagnostics. This may help for identification of disease that can develop in future.

VI. **Biological Engineering** (Kundu et al. 2014)
Biomaterials of either natural or synthetic origin are used to fabricate implantable devices, which are carriers for bioactive molecules or substrates to play an important role in tissue regeneration. These bioengineered species show better biocompatibility, flexible mechanical properties and strength, easy scalability, non-toxic products and by-products, etc. Such engineered products are also used as film coating materials on implants that extends its life and prevents wear and tear. Due to their advantageous properties, they may actually be used to develop artificial organs in future.

VII. **Medical Devices** (Harris and Graffagnini 2006)
Nanomaterials are under investigation for modern medical devices. These devices will act as multipurpose devices that will ensure diagnostics along with its routine purposes. Implantable devices such as stents and catheters will be part of these

nanotech-enabled medical devices with an aim to provide convenient real-time diagnosis of disease. Such diagnosis can be done at a clinic rather than at a laboratory. Besides, such implantable devices will cause less irritation and have more improved functionality.

1. **Medical devices in diagnostics**: In the coming years, nanotechnology will enable a shift to preventive medicine and the use of "point of care" diagnostics to quickly identify diseases. Portable diagnostic kits will become available to test whether individuals are genetically predisposed to a specific disease or have the earliest indications of a disease. Nanosphere, Nanomix and Alpha Szensors are a step closer towards such diagnostics. A large number of universities are promoting development of such sensitive sensors for rapid detection of diseases.
2. **Implantable medical devices:** Medical devices such as catheters, stents, and orthopaedic implants are always in risk to get infected with bacteria and microorganisms. Such infections can be responsible for serious illness and may require removal or change of the infected devices. Besides, it requires surgery or other medical procedures that is time consuming and risks patient's life. More than half of all nosocomial infections are caused by implanted medical devices. AcryMed uses silver nanoparticles that prevent formation and accumulation of bacteria. Such bacteria-protecting biofilms on the surface of medical devices are always advantageous.

   Similarly, bone surgeries, such as hip or joint replacements, often use titanium implants. It is quite common that muscle tissue fails to adhere to smooth surface of titanium, which leads to a lack of comfort over a period of time. Altair Nanotechnologies and National Research Council of Canada are working together to develop coating for orthopaedic implants. For this, Altair's nanoscale titanium dioxide is being used as a core material. Coating exhibits improved mechanical properties such as hardness and bond strength when compared with existing implant coatings such as hydroxyapatite. Additionally, these coating shows higher biocompatibility with bone cells that could result in longer lifetime of the implant. Also, Altair is looking forward to sell zirconium oxide nanoparticles for dental applications that can be used as fillings and in prosthetic devices.

   A problem associated with cardiac stents is that they are prone to clog again with fat after they have been implanted. Using stents that can elute drug stored in them in the form of nanoparticles entrapped in polymer is another attempt to solve this problem. Also, nanostructured materials offer opportunities to enhance the surface areas of medical devices to address these problems. Nanotech Catheter Solutions develop catheters and stents using carbon nanotubes ('CNTs'). Matrix of nanotubes might be used to replace polymer-coated stents that provide a non-biodegradable mechanism for slow-continuous release of a drug.

   Nanoparticle-based bioactive coatings are expected to improve mechanical and osteoconductive properties for both dental and orthopaedic implant applications (Saji et al. 2010)

VIII. **Cytogenetics** (Ioannou and Griffin 2010)

Cytogenetics, a branch of genetics, is a study of how chromosomes relate to cell and cell behaviour, particularly during mitosis and meiosis. The recognition of specific chromosomal patterns has widespread applications, and it helps to understand the fundamentals of cell and cell cycle. Development of cytogenetics in the molecular era has begun after development of FISH *(fluorescent* in situ *hybridisation)*. FISH is a technique that allows to identify direct DNA sequences which are present on chromosomes, and gene mapping is based on this principle. It further facilitates chromosome painting (helps to differentiate chromosomes), advanced diagnostics (identification of chromosomes responsible for disease and disorder), and comparative genomics (for comparison across different species and variation related to them). However, FISH techniques have poor resolution due to use of organic fluorophores. This leads to overlapping of spectra, photo bleaching, etc. These problems have been solved to certain extent using quantum dots. Quantum dots (QDs) are novel inorganic fluorochromes which are nanocrystals made from semiconductor material. They are resistant to photo-bleaching and have narrow excitation and emission wavelengths that can be controlled by particle size. In short, they have the potential for improvising the sensitivity of experiments and are ideal material for FISH analysis and molecular cytogenetics (Ioannou and Griffin 2010).

IX. **Gene Therapy** (Herranz et al. 2012):
Gene theranostics, a newer field that is an amalgamation of nanoparticles, gene therapy, and medical imaging, uses a nanobioconjugate for diagnosis and treatment. The process involves binding of a vector carrying genetic information with a nanoparticle. This nanoparticle provides the signal for imaging. The synthesis of this probe improves the efficiency and quality of gene transduction and imaging contrast. The application of such techniques in biomedicine leads to newer concepts in nanomedicine and theranostics, which can combine diagnosis and therapy in a single probe. Magnetic resonance imaging (MRI) is one of the most sophisticated tools for diagnosis and monitoring of many diseases, which provides excellent anatomical resolution, and multiple physical methods are available to obtain contrast. In addition, the use of molecular probes can improve its sensitivity multiple folds for identifying the genes.
Besides, the success of gene therapy depends on the transgenes to be expressed and the delivery vectors used. Successful gene therapy depends on two important aspects.

(a) Efficient and safe delivery of genes at targeted cells.
(b) Effective monitoring of modified cells or modifying agents by non-invasive imaging techniques. This will allow tracking of gene delivery and gene expression.

The ability of a vector to cross numerous barriers and reaching the targeted site can be improvised by using magnetic nanoparticles and their properties. Besides, bioconjugates of iron and gold have been successfully prepared and utilised in various phases of gene therapy.

X. **Nanobioinformatics** (Maojo and Fritts 2012)**:**
Nanobioinformatics can be defined as application of nanotechnology in modern medicine and computers simultaneously, with an intention to gather information and improvise the overall healthcare system. Various areas where significant research in informatics is applied to nanomedicine that are already underway includes:

- Nanoparticle characterisation
- Modeling and simulation
- Imaging
- Terminologies, ontologies, and standards
- Data integration and exchange
- Systems' interoperability
- Data and text mining for nanomedical research
- Linking nano-information to computerised medical records
- Basic and translational research
- Networks of international researchers, projects, and labs
- Nanoinformatics education
- Ethical issues

In this new context (biomedical or nanomedical), nanoinformatics refers to the use of informatics techniques for analysing and processing information about the structure and physico-chemical characteristics of nanoparticles and nanomaterials, their interaction with their environments, and their applications for nanomedicine.

XI. **Neuroscience** (Silva 2006)
Neuroscience is one of the most complicated fields in biomedical, which is not completely understood yet. However, neuroscience can be simply defined as study that correlates to neurons. The challenges associated with nanotechnology applications in neuroscience are numerous, but the impact it can have on understanding how the nervous system works, how it fails in disease, and how we can intervene at a molecular level is significant. The ability to exploit drugs, small molecules, neurotransmitters, and neural developmental factors offers the potential to tailor technologies to particular applications that may help to treat various CNS disorders. A significant challenge in in vivo applications of nanotechnology is that they are designed to physically interact with neural cells at cellular and subcellular levels, but ultimately aim at engaging functional interactions at a systemic level, which usually involves large groups of interacting neurons and glia. Although technically and conceptually challenging, these types of applications could have a significant impact on clinical neuroscience.

XII. **Microbiology, Virology, and Immunology** (Allahverdiyev and Rafailovich 2011)
The worldwide escalation of bacterial resistance to conventional medical antibiotics is a serious concern for modern medicine. High prevalence of multidrug-resistant bacteria among bacteria-based infections decreases effectiveness of current treatments and causes thousands of deaths. New improvements in present methods and novel strategies are urgently needed to cope with this problem. Owing to their antibacterial activities, metallic nanoparticles represent an effective solution for overcoming bacterial resistance. However, metallic nanoparticles are toxic, which causes restrictions in their use. Recent studies have shown that combining nanoparticles with antibiotics not only reduces the toxicity of both agents towards human cells by decreasing the requirement for high dosages but also enhances their bactericidal properties. Combining antibiotics with nanoparticles also restores their ability to destroy bacteria that have acquired resistance to them. Furthermore, nanoparticles tagged with antibiotics have been shown to increase the concentration of antibiotics at the site of bacterium–antibiotic interaction and to facilitate binding of antibiotics to bacteria. Likewise, combining nanoparticles with antimicrobial peptides and essential oils generates genuine synergy against bacterial resistance.

So, nanotechnology can be a key to avoid growth of resistant microbes and play a major role in immunisation and designing of therapeutic guidelines.

XIII. **Water Treatment** (Amin et al. 2014)**:**
The supply of freshwater is limited all across the globe. It is essential to manage the freshwater, which accounts only 0.5% of total water available across the globe. Also, it is essential to save this freshwater from wasting to ensure a healthy life. Freshwater can be saved by two major ways:

1. Increasing the availability of freshwater
2. Preventing mixture of waste water in this available freshwater

Various methods that involve nanoparticles to attain this are as follows:

1. **Disinfection:** Biological contaminants can be classified into three categories, namely, microorganisms, natural organic matter (NOM), and biological toxins. Contamination from bacteria, protozoans, and viruses is possible in both groundwater and surface water. The toxicity of the standard chlorine chemical disinfection in addition to the carcinogenic and very harmful by-products formation. There are many different types of nanomaterials such as Ag, titanium, and zinc capable of disinfecting waterborne disease-causing microbes. Due to their charge capacity, they possess antibacterial properties. Silver nanoparticles are derived from its salts like silver nitrate and silver chloride, and their effectiveness as biocides is documented in the literature. TiO_2 nanoparticles are among the emerging and most promising photocatalysts for water purification. CNTs (one of nanosorbents) which have been used for removal of biological impurities have received special attention for their excellent capabilities of removing biological contaminants from water. Filtration membranes containing radially aligned CNTs are very effective in removing both bacteria and viruses in very short time due to size exclusion and depth filtration and thus enable such filters to be used as cost-effective and point-of-use water disinfection devices.
2. **Desalination:** Desalination is considered an important alternative for obtaining freshwater source. Nanomaterials are very useful in developing more efficient and cheaper nanostructured and reactive membranes for water/wastewater treatment and desalination such as CNT filters. Nanomaterials offer opportunities to control the cost of desalination and increase its energy efficiency, and among these are CNTs, zeolites, and graphene which are the most effective.
Besides, nanoparticles are also useful in controlling waste management, which includes:

- Infectious waste
- Pathological waste
- Pharmaceutical waste
- Genotoxic waste
- Heavy metals and genotoxic waste

XIV. **Pathology and Toxicology**
Because of increased use of nanotechnology, the risk associated with exposure to nanoparticles, the routes of entry, and the molecular mechanisms of any cytotoxicity need to be well understood. In fact, these tiny particles are able to enter the body through the skin, lungs, or intestinal tract, depositing in several organs and may cause adverse biological reactions by modifying the physiochemical properties of living matter at the nano level. In addition, the toxicity of nanoparticles will also depend

Table 2.1 Nanoparticles in medical developments

Tests using nanoparticles	Used for
Nanosized exosomes	Diagnosis of pancreatic cancer
Nanopore sensors	Identification of viruses
Nanoflares	Diagnosis of cancer cells
Nanowire-based sensor	Diagnosis of prostate cancer
Magnetic nanoparticles	Diagnosis and tumour targeting
Carbon nanotube	Protein indicative oral cancer
Gold nanoparticles	Flu virus
Quantum dots	Diagnosis of cancer cells
Silver nanorods	Separation of viruses and bacteria

on whether they are persistent or cleared from the different organs of entry and whether the host can raise an effective response to sequester or dispose of the particle. Hence, it seems reasonable to evaluate the risk/benefits ratio for the use of nanoparticles in any technological or medical developments Table 2.1.

XV. **Cosmetics** (Prajapati 2011)
Nanoparticles have been identified as a potential next generation cosmetic delivery agent that can provide enhanced skin hydration, bioavailability, stability of the agent, and controlled occlusion. Presence of nanoparticles in cosmetic industry is observed in a wide range of products that includes sunscreens, breast cream, hair care, make-up, moisturising creams, anti-wrinkle cream, toothpaste, face wash and face masks, deodorants and perfumes, lipsticks, blush, eye shadow, nail polish, foundations, after-shave lotions, etc.

2 Conclusion

The current review is a general overview on application of nanoparticles in biomedical and healthcare. Nanoparticles are minute particles that produce a major change in the healthcare and biomedical industry. It is not restricted to any field and its presence is observed in every field of biomedicine from diagnosis to treatment to implants to cosmetics. Besides, it also includes daily needs such as water treatments, pollution control, and waste management. Nanoparticles and fields associated with it are growing at an exponential rate, and this may continue based on its advantages and numerous applications.

Research in the field of nanoparticles promises some great results and its impact will be observed in the years to come. The future of healthcare will be based on the fact of identification of disease in the very early stage and therapies will be more patient compliant. Nanoparticles will provide flexible, modern, and more suitable therapies with minimal adverse effects and maximum therapeutic effects. It will not be restricted to healthcare and will also focus on improving the overall standard of living. It offers space for cleaner, greener, and safer planet.

The enhanced hardness and strength of nanomaterials in comparison with their coarser counterparts is attractive in making high wear resistance implants. Nanoceramic coatings are attractive in terms of enhancement of mechanical properties (hardness, toughness, friction coefficient, etc.) Carbon nanotubes and nanofibers have been investigated as reinforcement material. The versatility of these fibres suggests that there are a large number of possibilities for future designs that could enhance the efficiency of medical implants.

To sum up, nanoparticles over a much wider space to cover and current knowledge just seems to be the tip of the iceberg. As newer research projects will carry forward, more groundbreaking outcomes can be expected.

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