



# NANOTECHNOLOGY IN ADVANCED MEDICAL APPLICATIONS

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## 1. Introduction

Understanding and manipulating matter at dimensions between 1 and 100 nm, where special phenomena allow for fresh applications, is referred to as nanotechnology. Richard Zsigmondy, was the one who initially coined the term "nanometre." He was the first to use a microscope to measure the size of particles like gold colloids. With four generations of products with growing structural and dynamic complexity—passive nanostructures, active nanostructures, nano systems, and molecular nano systems— nanotechnology is already progressing toward becoming a general-purpose technology. The rapid growth of nanotechnology throughout the world is evidence of the revolutionary potential of spotting a notion or trend and outlining a vision at the synergistic intersection of various study fields (Hulla 2015, Roco 2011).

Top – down and Bottom– up method are the two main approaches adopted for the synthesis of nanoparticles. Top-down method is the approach of nanoparticle production where bulky materials which can be effectively used for required purpose are broken down or disintegrated to nanoscales using different methods. Another approach called Bottom –up is the method of producing nanoparticles by integrating smaller sized particles to form nanoscale particles that act as nanoparticles.

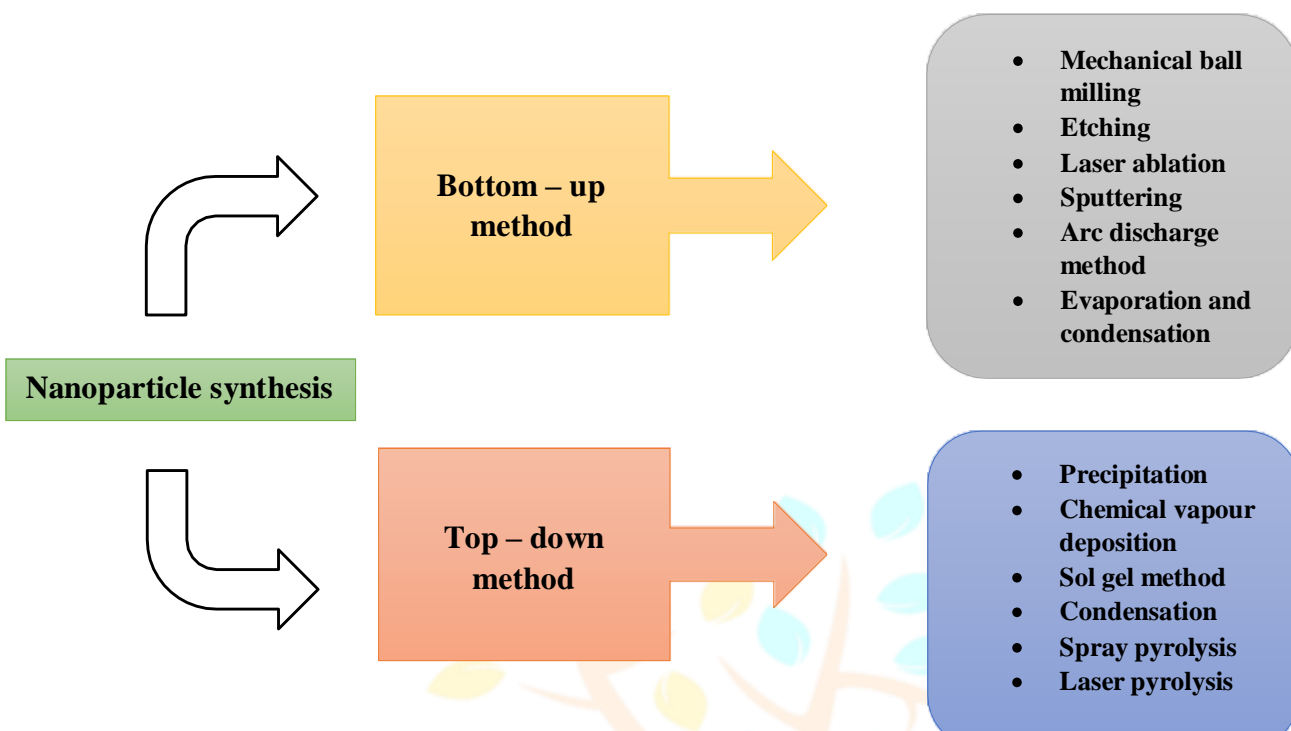
One-dimensional (thin films), two-dimensional (nanofibers, nanowires, nanotubes, etc.), and three-dimensional (nano powders, nano capsules, fullerenes, dendrimers, precipitates, colloids, quantum dots, nanostructured materials, nano porous materials, etc.) materials are all included in the category of "nanomaterials" (Sathiyapriya 2019). Nanotechnology has produced materials that can be used for molecular-level diagnostics and treatment, tissue replacement, and organ reconstruction. Another exciting use for nanoparticles is in the development of nanobiosensors, which incorporate many of the advantages of nanomaterials into the biosensor field (Challa 2018). Nanometallic particles are employed in the production of antibacterial, catalytic, and conductive screen layers, sensors, and energy materials. In the fields of electronics, optics, catalysis, the bio-medical industry for tracing or even implant- type applications, nano porous is

employed as aerogels for thermal insulation. Single-walled nanotubes are employed in conductive adhesives and connectors, structural materials, ceramic applications, tyre and optic industries, and electrically conductive nanocomposites. Massive nanomaterials are employed in structural parts for the automobile, oil and gas, sports, anti-corrosion, and aerospace industries as well as hard coatings and pipelines. Dendrimers are utilized in cosmetic products, medicine administration, and fast detection in the medical industry. Quantum dots are employed in type marking and anti-counterfeiting applications in optoelectronics (screens), photovoltaic cells, inks, and paints. Fullerenes have numerous applications in the health care industry, including use as excellent anti-oxidants, antiviral agents, drug and gene delivery, photosensitizers in photodynamic therapy, and polymers with optical limiting properties. They are also used in the development of photovoltaic solar cells, as hardening agents for the creation of lightweight materials, and in the manufacture of sports materials (surface coating and photoconductive devices in particular for applications in artificial photosynthesis). The conductive layers of screens, solar cells, and electrical gadgets all use nanowires (Sathiyapriya 2019).

## 2. WHY NANOTECHNOLOGY IS USED IN MEDICAL FIELD?

Because they provide better- i) built, ii) safer and cleaner, iii) longer-lasting, and iv) smarter goods for the medical, communications, daily life, agricultural, and other industries. Drug delivery is the main and most effective application of nanotechnology due to the combination of pharmacokinetics and pharmacodynamics. Nanotechnology uses nanoparticles to deliver medications to specific locations. This incredibly selective approach can reduce costs and lessen patients' suffering. Nanoelectromechanical systems are also employed for the active release of pharmaceuticals. Iron nanoparticles or gold shells have important uses in the treatment of cancer. A customized medication plan minimizes drug consumption and healthcare expenses, lowering the cost of patient care (Nikalje 2015).

Drugs are frequently administered to a specific target place during therapy. If there is no internal channel for drug delivery, external therapeutic approaches including radiotherapy and surgery are used. To combat diseases, these techniques are frequently combined or used interchangeably. The aim of treatment is to permanently eliminate the tumors or illness-causing factors through targeted removal. Control of drug release and targeting capabilities make up the ideal drug delivery system. By properly identifying and eliminating dangerous or malignant cells, side effects can be drastically avoided, and drug efficacy can be guaranteed. The negative effects of medications can also be lessened with regulated drug release. Because of their small size and ability to be delivered via intravenous and other methods, nanoparticle drug delivery systems have the advantages of reducing irritating reactions and improving penetration within the body. These methods have produced successful outcomes, showing improved drug bioavailability, targeted drug delivery, and uptake of low solubility drugs. The specificity of nanoparticle drug delivery systems is made possible by attaching drugs to nano-scaled radioactive antibodies that are complementary to antigens on the cancer cells (Sim 2021). Figure 1 shows the different forms of nanoparticles used in medical field for diagnostics as well as therapeutic purposes. The effect of nanoparticles depends on its formulation and mode of delivery were, it would determine whether the drug should be delivered inside the cell or outside the cell, in the blood or target tissue, drug infusion at the time of delivery or delayed infusion etc.



**Figure 1.** Two approaches of the formation of metallic nanoparticles Top - down and Bottom-up

### 3.NANOTOOLS

The nanoparticles available in the surroundings as well as extracted once are formulated into different forms on the basis of functions, shape, structure etc which are nano-tools used in different fields of medicine, industries etc (Fig.2).



**Figure 2.** Commonly used NPs in biomedical sciences

### 3.1. DENDRIMERS

Dendrimers are well-researched polymeric compounds that have specific chemical structures and particular physical characteristics. A nanometer-sized round polymer macromolecule is known as a dendrimer. Different surface groups with hydrophobic or hydrophilic components may either encapsulate or bind to ligands to protect them from degradation. After creating a compound with a dendrimer, drug molecules can be delivered to target cells and then released from the complex. Dendrimers can improve a drug's bioavailability by modifying a drug's surface charge, making it more soluble in water, and lowering its toxicity. Dendrimers are capable of transferring a wide variety of biomolecules, including proteins, peptides, enzymes, gene material, and others, to the target cells. They also work well in gene therapy, medical imaging, and immunology. Numerous studies have demonstrated that dendrimers are more efficient than liposomes, viral vectors, and linear polymers at delivering different kinds of biomolecules (Pedziwiatr-Werbicka 2019). They are composed of central core, branching units, and terminal functional groups. They can also be "decorated" with polyethylene glycol chains to make them more stable and immune to phagocytes (Chauhan 2018).

### 3.2. NANO SCAFFOLDS

By manipulating cell connections, regulatory signals, and scaffold materials, tissue engineering can precisely restore natural tissue shapes and functions. The scaffolds were made of biodegradable materials and featured a porous structure that would allow host-cell colonization. Nanofiber scaffolds are one of the prospective constructions that could replace the natural extracellular matrix when compared to other approaches (ECM). These Nanofibers can be made from synthetic, natural, or a combination of the two types of materials. Nanofibers can be produced using a variety of efficient methods, such as electrospinning, phase separation, and self-assembly. Numerous artificial and organic polymers have been used as building blocks to create 3D matrices for tissue healing. These materials include synthetic biodegradable polymers like poly-L-lactic acid (PLLA),  $\epsilon$ -caprolactone (PCL), and PGA as well as natural polymers including collagen, silk, and DNA (Anusiya 2022).

### 3.3. NANOSHELLS

The most useful nano shells may easily penetrate several centimeters of human tissue and can absorb near-infrared light. Because of their capacity to absorb light, nano shells produce intense heat that kills cells. Nano shell materials can be constructed using insulators, metals, and semiconductors as the basic constituents. The qualities of a nano shell depend on the materials used and the core-to-shell ratio. Metallic nano shells are made of metal, especially gold ones. Metallic shells surround dielectric cores in metal nano shells, especially those made of gold (AuNSs). The drug is either enclosed within specific functional groups or stabilized electrostatically before being adsorbed onto the shell's surface. Surface functionalization of AUNs becomes possible through the advancement of surface coating technology. Various functional groups, including PEG, ssDNA, antibody, peptide, drug, fluorescence marker and siRNA can be conjugated or attached to the surface of particles, allowing for specific applications like

molecular sensors, therapeutic agents and vehicles for imaging agent and drug delivery. In the clinical experiment, it was shown that photothermal therapy based on gold-silica nano shells (GSN) was effective at controlling tumors (Sarkar 2020, Singla 2021).

### 3.4. NANO-EMULSIONS

Nanoemulsions have a wide range of applications as drug delivery systems because of a number of their distinctive characteristics. Nanoemulsions have proved useful in the production of different dosage forms, such as liquids, foams, and creams, due to their compatibility, ability to dissolve a greater number of lipophilic medicines, and protection from enzymatic degradation and hydrolysis. They are also thought to be the best medicine delivery vehicles. They offer increased spreading, wetting, and penetrating qualities in addition to being straightforward and homogenous to deposit on substrate surfaces due to the low surface tension of the overall system and the lowered interfacial tension between the oil and water phases. It is believed that the Nano emulsions droplets' small size has a significant impact on their stability (Makkithaya 2022).

### 3.5. SOLID LIPID NANOPARTICLES (SLNs)

SLNs are physiological lipid-based sub-micron colloidal carriers with diameters ranging from 50 to 1000 nm that are dispersed in water or an aqueous surfactant solution. Solid lipid nanoparticles (SLNs), formerly known as lipospheres, are one of the promising pharmaceutical nanocarriers for controlled drug delivery.

SLNs typically consist of biodegradable and secure lipidic components. The ability of SLNs to transport a variety of medications, including small pharmacological compounds, large biomacromolecules (polysaccharides, etc.), genetic material (DNA/siRNA), and vaccine antigens, is one of its special qualities (Sarangi 2016).

### 3.6. QUANTUM DOTS

Quantum dots (QDs) have drawn a lot of interest in biological research due to their many advantages over conventional fluorophores. Quantum yield (QY) with excellent resistance to photobleaching and degradation, effective light absorption across a broad-spectrum size-hanging and spectrally restricted light emission (Xuewen 2014). Bottom-up colloidal synthesis is the most common technique for producing highly dispersed QDs for use in biological applications. Nucleation, growth, and termination are the three phases in the formation of colloidal QDs. Due to their great monodispersity, large quantum yields, and narrow emission peaks, QDs are better for bioimaging applications. This method has been used to produce QDs made of several elements, including cadmium (Cd), indium (In), and lead (Pb). Numerous biomolecules, such as nucleic acids, peptides, proteins, and polysaccharides, have been used as templates to produce QDs (Alaghamdard 2021).

### 3.7. MAGNETIC NANOPARTICLES

For biomedical applications such as drug administration, magnetic resonance imaging, magnetic-activated cell sorting, nano biosensors, hyperthermia, tissue engineering, and regenerative medicine, the inherent features of magnetic nanoparticles (MNPs) of iron oxide have been successfully used. The size and form of nanostructures have a major impact on the physical and chemical properties of superparamagnetic iron oxide nanoparticles.

Magnetic iron oxide nanoparticles (MIONs), also known as magnetite ( $\text{Fe}_3\text{O}_4$ ) or maghemite ( $\text{gFe}_2\text{O}_3$ ), have found usage in a range of fields due to their low toxicity, excellent biocompatibility, and distinctive mechanical, magnetic, chemical and thermal effects under varied applied magnetic fields. The anticancer drug doxorubicin can form electrostatic interactions with negatively charged groups on magnetic nanoparticles through ionic bonds, creating a promising nanosystem for targeting and treating acidic solid tumors (Ali 2016, Ajinkya 2020).

### 3.8. CERAMIC NANOPARTICLES

Ceramic nanoparticles, also known as nanoceramics, are inorganic, heat-resistant, non-metallic solids that contain both metallic and non-metallic components. They are made by continuously heating and cooling materials. Ceramic nanoparticles could prepare in different ways including biomimetic deposition, microemulsion, sol-gel process, electrodeposition, Mechanochemical synthesis. They can be amorphous, polycrystalline, dense, porous, or hollow, among other morphologies. In medical technology, nanoceramics are utilized to repair fractured bones. Additionally, ceramic NPs are used to produce and store energy as well as technologies for communication, transportation, building, and medicine. Their electrical properties might make it possible for energy to be transmitted with nearly perfect efficiency (Thomas 2015).

### 3.9. FULLERENES

A variety of water-soluble fullerene derivatives have been developed, produced, and used as drug delivery systems, antiviral agents, bioimaging agents, and photodynamic therapy agents (Zhang 2019).

## BASIC APPLICATIONS OF NANOTECHNOLOGY

The basis for amazing industrial applications and exponential growth is now nanotechnology. For instance, nanotechnology has had a significant impact on medical equipment like imaging probes, drug delivery systems, and diagnostic biosensors in the pharmaceutical communities of practice. The usage of nanomaterials has significantly risen in the food and cosmetics industries for enhancements in manufacturing, packaging, shelf life, and bioavailability. Nanoparticles are currently employed as food sensors for determining the quality and safety of food since they have antibacterial action against bacteria that are present in food. Zinc oxide quantum dot nanoparticles have this ability (Bhushan 2017). To investigate the advantages and dangers of using nanoparticles in medicine and medical devices, the field of nanomedicine was created. This field comprises subfields including tissue engineering, biomaterials, biosensors, and bioimaging. Improved medication delivery, antimicrobial coatings for medical equipment, less inflammation, better surgical tissue repair, and the identification of circulating cancer cells are just a few of the potential advantages of medical nanomaterials (Hulla 2015).

## 4. APPLICATIONS IN THE MEDICAL FIELD

Early illness detection and prevention, better disease diagnosis, appropriate therapy, and follow-up are all made feasible by nanomedicine. The use of specific nanoscale particles as tags and labels allows for rapid and efficient biological testing that is also more sensitive and adaptable. The development of nanotechnology has increased the efficiency of gene sequencing. The use of nanotechnology allows for the replication or repair of damaged tissue. Tissue engineering, which might revolutionize organ transplantation or the use of artificial implants, uses so-called artificially activated cells. Even today, many significant and complicated diseases pose a serious threat to humanity, including diabetes, cancer, Parkinson's disease, Alzheimer's disease, cardiovascular disorders, multiple sclerosis, and numerous chronic inflammatory or infectious diseases (such as HIV)

### 4.1. NANOTECHNOLOGY- DIAGNOSTICS AND TREATMENT

Future advances in molecular nanotechnology will be made possible by nanomedicine. The development of nanotechnology has increased the efficiency of gene sequencing. The use of nanotechnology allows for the replication or repair of damaged tissue. Tissue engineering, which revolutionizes organ transplantation or the use of artificial implants, uses so-called artificially activated cells (Yezdani 2018). Improved fluorescent markers for screening and diagnosis are one of the nanomedicine's applications. Conventional fluorescent markers need complicated colour-matched lasers, which are limited in their ability to distinguish between colours because dye bleeds after only one use. These problems may be resolved by fluorescent nanoparticles like quantum dots, PEBBLES (probes enclosed by physiologically localized embedding), and perfluorocarbon particles.

### 4.2. NANOMEDICINES

The biological assessment of nanomedicines considers factors such as immunogenicity, specific therapeutic concerns, the resistance of non-degradable systems, and biodistribution. Nanomedicines can be created as physiologically active medicinal products or drug delivery systems. They are complex systems at the nanometer scale with at least two components, one of which is the active ingredient. Drug delivery is an interdisciplinary field of study with the goal of making complex novel drug administration practicable and improving the marketability of already available medications (Basit 2021).

### 4.3. USE OF NANOPARTICLES IN DRUG DEVELOPMENT AND DELIVERY SYSTEM

Drugs based on nanotechnology are especially created to lessen toxicity and enhance health results. Additionally, solid NPs imply significant benefits in medication development due to their biophysical stability and the potential to alter drug formulation to enable controlled drug release. The aliphatic polyesters, including poly (lactic acid), hydrophilic poly (glycolic acid), and their copolymers, maybe the most commonly utilized (lactide-coglycolide). The stability of medications can be improved by NPs in the dose by maintaining their particle size during their whole self-life, which is essential for effective development (Nikalje 2015). The formulation of the particular drug-targeting system is based on an appropriate concentration, therapeutic effectiveness, and a prolonged circulation period. This effective medication targeting strategy was developed

by using the pathophysiological modulation that occurs with the progression of illnesses. The binding and distribution of medications to specific locations may be facilitated by this tailored delivery. When creating a target-specific drug delivery system, organic, inorganic, metallic, and polymer-based NPs including liposomes, micelles, and dendrimers are frequently considered. These NPs have the ability to initiate the potential drug delivery in medications with poor solubility and limited absorption (Mirza 2014). Later, a number of NPs-based medication carriers emerged, and several are now being studied for a variety of disorders. There are several NP-based therapeutic drug delivery systems in use today that have been specifically formulated as polymer micelles, emulsions, and solid particles. Some nano-based medications, including Caelyx, Doxil, Transdrug, and Abraxane, are marketed for the treatment of cancer.

Two different delivery methods can be utilized with the NPs to transport the compounds they are laden with: (1) encapsulation using lipid- or polymer-based capsules, and (2) polymer-based structures employing natural or synthesised polymers. In terms of diagnostics and treatments, NPs generally have a number of benefits over traditional preparations. They are generally safer and biocompatible. They are able to successfully destroy intracellular and multiple drug-resistant bacteria by crossing the BBB and other physiological barriers. They offer fresh methods for developing vaccines and gene therapy (El-Sayed 2020).

The main use of nanotechnology for drug delivery has been concentrated in NPs, which are primarily suggested for the treatment of tumors. It is non-invasive, oral administration is the ideal method for drug delivery. Due to the acidic environment of the stomach, oral protein or peptide medication administration has not yet been achieved. To get beyond these obstacles in medicine delivery, however, nanotechnology will be used to encapsulate such medications in nanoparticles. Additionally, it improves medication site-specific targeting, preventing the delivered drug's accumulation to lessen the off-target effect (Sahu, 2021). After being injected into the bloodstream, NPs engage in extensive physiological interactions, including those with plasma proteins. Since they are quickly removed from the bloodstream by the mononuclear phagocyte system (MPS) or complement system, the medication will release at off-target sites as a result of the premature clearance. The blood circulation half-life of nanomaterials can be increased by avoiding immune system detection and clearance by grafting a stealth coating layer onto the surface of NPs. For effective medication delivery to lower systemic toxicity and enhance pharmacological profiles, the regulated delivery of therapeutic agents to tumor cells utilizing nanocarriers is crucial. NPs must be able to avoid being phagocytosed by the MPS, formerly known as the reticuloendothelial system, which includes monocytes and macrophages, in order to stay in the bloodstream until they reach the therapeutic location (RES). Therefore, achieving effective drug delivery is greatly hampered by the MPS's ability to opsonize or remove nanocarriers from the bloodstream. Upon intravenous delivery, the MPS can remove the majority of unprotected NPs from the blood circulation within seconds to minutes, regardless of the components that make up their composition. NPs themselves cannot be captured by macrophages, but they can detect the opsonin proteins attached to their surface (Fam 2021). To prevent the elimination of NPs from the system, they are introduced in different forms in the body so that they can persist in the bloodstream away from the attack of the immune system.

#### 4.4. BIOIMAGING

Some nanomaterials may represent a new class of bioimaging probes with enormous potential for use in disease early-stage diagnostics. Clear visible emission lines, long fluorescence lifespan, superior photo-stability, and high signal-to-background ratio are employed in nanotechnology to visualize non-invasive and deep tissue penetration. Up-conversion nanoparticles (UCNPs) with lanthanide (Ln) doping were said to have many advantages over traditional fluorophores, including low cytotoxicity, no photobleaching, no photo-blinking, and good spatial resolution. Fluoride-based UCNPs have also been noted as one of the modern day's most effective up-conversion fluorescent nanoparticles due to the low vibration energy (Gun'ko 2016). Graphene has garnered the most interest of all the nanomaterials that are being evaluated as prospective options for nano-bioimaging applications. The biological uses of graphene and its derivatives are being thoroughly researched for diagnostics, drug transport, near-infrared (NIR) light-induced photothermal treatment, and bioimaging, as it has been stated by Lin et al. Graphene and its derivatives can easily be functionalized by small-molecule dyes, polymers, nanoparticles, medicines, or biomolecules to produce graphene-based nanomaterials for various bioimaging applications because of its diverse surface functionalization and ultrahigh surface area. Lanthanide-doped up conversion nanoparticles can be utilised for magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET)/single photon emission computed tomography, just as other semiconductor nanocrystals like CdS, ZnO, TiO<sub>2</sub>, and CdSe/ZnS core shells (SPECT) (Ghamsari 2018).

#### 4.5. SURGERY – NANOBOTS

Microbes that ride on its metabolism and manipulate biologically based robotics can even cause the constructed biomachine to perform a new or different function than it was designed to. By isolating pathogens or assessing the physical properties of tissue in real-time, micro/nanorobots have the potential to aid in medical diagnosis by providing an accurate diagnosis of disease and critical signals. Micro/nanorobots during surgery might access parts of the body that catheters or invasive procedures could not, enabling the delivery of therapeutic payloads deep inside diseased tissue or the sampling of tissue (Soto 2020).

#### 4.6. NANODIAGNOSTICS

The new word "nano diagnostics" refers to the application of nanotechnology's ideas and approaches to diagnostics. It involves identifying the pathophysiology of the ailment and the organisms that are responsible for it, as well as determining the disease status and any susceptibility to it. Nanoscale diagnostics made possible by nanotechnology has sparked a trend toward the usage of readily available, marketable handheld gadgets. The development and optimization of nanoparticle platforms for the detection of pathogens and cancer biomarkers has resulted in less laborious but more sensitive diagnostic procedures because the majority of complex procedures are now integrated onto a single, straightforward device that can be used for immediate diagnosis (Jackson 2017).

#### 4.7. NANOTECHNOLOGY IN GENE DELIVERY

The major use of nanotechnology in drug delivery has been concentrated in NPs, which are mostly advised for the treatment of tumors (Devulapally 2014). It has been hypothesized that NPs have significant potential as vectors to carry various molecules, such as DNA, RNA, etc., as a result of the development of nanotechnology. A variety of nanomaterials based on lipids (lipid nanoemulsions, solid lipid nanoparticles), polymers (such as PEI, PLGA), graphene, carbon nanotubes (CNTs), nanospheres, and various inorganic particles have been employed as gene delivery systems. Due to their sustained effect of gene delivery in the target tissue and higher genetic material stability, functionalized varieties of nanomaterials-based gene delivery platforms are thought to be the most promising systems. Although NP-based gene delivery systems hold enormous potential for treating a number of fatal hereditary and acquired disorders, the Food and Drug Administration has not yet authorised any such device (FDA). The low gene transfection effectiveness of nanoparticles *in vivo* and the unidentified long-term toxicity of nanomaterials are the causes (Kargozar, 2018).

#### 4.8. USE IN TRANSPLANTATION AND TISSUE ENGINEERING

Because of their low toxicity, adaptability, and manipulability, NPs present a fresh strategy to overcome a number of barriers that prevent effective transplantation. In cell and organ transplantation medicine, the main justification for employing targeted NP drugs or gene therapy is to reduce the negative systemic side effects of conventional pharmacotherapies while enabling the formation of a local microenvironment of tolerance. Lower systemic drug dosages; localized, sustained, controlled drug delivery; large functional surfaces for improved bioavailability and biodegradability; and packaging potent medications that are typically poorly soluble are some benefits of using NPs to overcome the challenges of transplant medicine. In PLGA NPs, mycophenolic acid preferentially bonded to dendritic cells and macrophages to upregulate PD-L1, which ultimately resulted in improved graft survival (100 percent survival at 20 days post transplantation). NPs localised in macrophages when testing an NP encapsulation of skin antigen to promote tolerance. However, the gold standard therapy utilising splenocytes produced better results and was able to involve CD11c+ B220+ dendritic cells (Yao 2020).

By enhancing the biological features of cells such as cell adhesion, proliferation, and differentiation, many research using nanostructured materials have demonstrated the viability of this technology and its utility in the regeneration of diverse tissues such as the heart, bone, nerve, etc. The extracellular matrix (ECM), whose components are structured into nanostructures such as triple helices, fibres, etc., with many bioactive factors controlling the homeostasis, surrounds the cells in the *in vivo* framework, which is a three-dimensional (3D) microenvironment (Gholami 2020).

#### 4.9. CANCER – DETECTION AND TREATMENT

One of the leading causes of death in the globe is cancer. Malignant diseases are thought to have caused 8 million fatalities in 2008, and by 2030, that number is expected to rise to 11 million. Traditional chemotherapies are highly effective, yet patients still have side effects and are extremely toxic to healthy cells while having little effect on malignant cells. Numerous inhibitors are available and being developed to target the enzymes

involved in the distinct signalling networks known to support and maintain cancer (Momenimovahed 2019). By employing nanoparticles and quantum dots, cancer nanotechnology offers a distinctive technique against cancer through early diagnosis, prevention, and individualized therapy. The identification of cancer biomarkers is significantly aided by nano-biotechnology. As a carrier of biomolecules that may detect cancer biomarkers, many materials including quantum dots, gold nanoparticles, magnetic nanoparticles, carbon nanotubes, and gold nanowires have been produced. Biomolecules such proteins, antibody fragments, DNA fragments, and RNA fragments serve as the foundation for cancer biomarkers in nanoparticle aided cancer detection and monitoring. In order to designate tumours with high empathy and specificity, numerous anticancer agents, including medicines and diverse biomolecules, can be combined with nanoparticles. This combination is helpful in the early detection and screening of cancer cells. Small-diameter nanoparticles have a huge surface area that makes it simple for them to connect to functional groups of various optical, radio isotopic, or magnetic diagnostic and therapeutic agents. This increases the validity and effectiveness of cancer diagnosis (Smart 2018). The most frequently utilized therapeutic nanoformulations for cancer chemotherapy currently on the market were Doxil, Daunorubicin (Daunoxome), and Abraxane. Paclitaxel is delivered by the albumin-bound nanoparticle Abraxane (Abraxis), and doxorubicin is delivered by the liposome-mediated drug delivery system Doxil. These two nanoformulations are frequently employed to treat metastatic breast cancer. It has been demonstrated that targeted liposomes containing folate receptors may overcome multidrug resistance in tumor cell lines and efficiently deliver doxorubicin in vivo (Sahu 2021). Nanoparticles and nanomaterials can be used to enhance biosensors to offer precise targeting. Cancer biomarkers have been found using QD-based biosensors. The distinctive qualities of QDs include their excellent photobleaching resistance, high quantum yield, high molar extinction coefficient, extensive absorption with narrow, high-efficiency Stokes shifts, and outstanding resistance to deterioration (Zhang 2019). Remarkable progress has been achieved in the production and characterisation of tailored nanoparticles for the imaging and treatment of tumours since the U.S. Treatments for cancer are radiation and immunotherapy-based combinations. Studies have shown that nanoparticle absorption is typically larger per unit tumour weight in smaller tumours. This elevated absorption is most likely the result of a small interstitial fluid pressure (IFP) and/or a macrophage milieu that is particularly enriched in tiny tumours (Grodzinski, 2019).

Nanoparticle imaging of tumour tissue has allowed for the early detection of malignancy in cancer diagnosis. By creating immune superparamagnetic iron oxide nanoparticles (SPIONs) that can be employed in MRI imaging and have the cancer cell lines as their target, it is possible to identify metastases in lung cancer. Recent research has demonstrated that SPIONs have a high specificity and no known adverse effects, making them acceptable building blocks for aerosols in MRI imaging of lung cancer (Jin 2020).

#### 4.10. STEM CELL THERAPY

Developments in nanotechnology in stem cell research indicate that new directions in regenerative medicine are on the horizon. To detect and photograph stem cells, promote their differentiation into a particular cell lineage, and eventually comprehend their biology, nanotechnology can be a useful tool. The development of

stem cell-based medicines for the prevention, detection, and treatment of human illnesses will hopefully result from this (Nikalje2015).

#### 4.11. OCULAR APPLICATION

One of the primary issues with topical ophthalmic medication administration is poor eye absorption, which makes it challenging to maintain a suitable drug concentration in the precorneal area. In comparison to conventional pharmaceuticals, which have a shorter half-life( $t_{1/2}$ ) in tear fluids (up to 1-3 min), nanoparticles exhibit enhanced durability and a longer half-life ( $t_{1/2}$ ) in tear fluids (up to 20 min). Nanoparticle drug delivery systems have the potential to increase the bioavailability of therapeutic drugs, reduce side effects, and maintain intraocular dose levels (Rizvi 2018). To create drug-injected nanoparticles with a size of around 100 nm, drug and polymer combinations have been mixed in ethanol and emulsified. In order to treat eye conditions, Silva and colleagues created and evaluated the effectiveness of a 0.75% w/w isotonic hydroxypropyl methylcellulose (HPMC) solution containing nanoparticles of chitosan, sodium tripolyphosphate, hyaluronic acid, and the antibiotic ceftazidime. These nanoparticles also induced cohesion, which led to effective interaction with the ocular mucosa and the release of antibiotics over a longer period of time. Nanoparticles may thereby lengthen the duration of the medication in the eyes.

#### 4.12. APPLICATION IN CARDIAC DISEASES

A category of illnesses known collectively as cardiovascular diseases (CVDs) includes atherosclerosis, myocardial infarction, stroke, hypertension, and heart failure. Some of the common techniques used to detect CVDs are plain X-rays, electrocardiography (ECG), computed tomography (CT), and magnetic resonance imaging (MRI). However, the limited specificity and sensitivity of these approaches render them ineffective. To get around these challenges, innovative methods including cardiac immunoassays and molecular imaging have been developed. Compared to traditional diagnostic procedures, nanotechnology offers considerable benefits. Early-stage CVDs can be identified using a combination of cardiac immunoassay and nanotechnology. It is possible to identify particular biomarkers of CVDs at an early stage by using nanotechnology in a variety of immunoassays, including the Electrochemiluminescence (ECL) Immunoassay, Fluorescence Immunoassay, and Enzyme-Linked Immunosorbent Assay (ELISA). Nanotechnology has the potential to decrease non-specific binding sites, have high-affinity cardiac targets, have adequate bioavailability, significantly amplify signals, and perform a variety of other tasks. These characteristics of nanoparticles enable them to move freely across low-restriction human bodies, therefore producing useful imaging vehicles and significantly enhancing the accuracy of diagnoses. Upon being injected or consumed, visible MOI-functionalized nanoparticles will spread throughout the body of the subject and will aim to diagnose various RNAs (Shi 2020).

#### 4.13. APPLICATION IN RESPIRATORY DISEASES

Nanocarriers can be used to successfully deploy drug delivery systems for respiratory illnesses like lung cancer, asthma, chronic respiratory diseases, cystic fibrosis, tuberculosis, and respiratory infections. NPs can enter the respiratory system by inhalation, disperse there, and then become lodged in the alveoli, where they

can approach and engage with the epithelial cells and pulmonary surfactant (PS). The mRNA vaccine delivered by lipid nanoparticles, which has already been in phase II and phase III clinical studies, is the first vaccine candidate recently introduced in clinical trials for the new coronavirus (SARS-CoV-2) (Wang 2018, Shin 2020).

#### 4.14. APPLICATION IN DERMATOLOGY

Numerous different nanomaterials have been synthesized, and they have been used specifically in the context of the cosmeceutical business. Nanodiamonds, nanoemulsions, nanosomes, nanoliposomes, metallic nanomaterials, polymeric nanomaterials, silica nanoparticles, nanocrystals, micellar nanoparticles, nano pigments, buckyball, are some of the often-utilized nanomaterials in the cosmetics business.

Allergens are captured or transformed into skin diseases using emulsions with active substances. Tolerance, such as atopic eczema, is the mechanism of the skin's protective barrier against irritants. Currently, doxorubicin is excreted through sweat glands, and nanoparticles are employed as an antioxidant carrier to protect the skin from this. Similar to how high lipid content moisturisers are less efficient in preventing water loss from the skin and reducing the risk of contact dermatitis in the hands, nanoparticle barrier creams frequently exhibit stronger occlusive effects and antioxidant action. Nanoparticle delivery methods have shown to play a crucial role in treating hair diseases by functioning as a reservoir for the medication's extended-release within the hair follicle openings, which is made possible by nanoparticles' enhancement of drug penetration. For the treatment of hair diseases including androgenic alopecia and alopecia areata, nanoparticle formulations are also thought to be more successful than alcohol and aqueous solutions currently in use. In comparison to aqueous control solutions, nanoparticles containing nutrients for hair development showed 2.0 to 2.5 times longer durability in hair follicle areas (Papakostas 2011).

#### 4.15. APPLICATION IN DENTISTRY

Checking on studies done in the dentistry field, Triclosan-loaded nanoparticles were able to enter the epithelial junction thanks to their implantation in dogs. calcium-deficient HA nanoparticles were used to create a better osteoconductive tetracycline delivery system.

Growth factors have also been employed therapeutically in dental tissues. As a growth factor carrier, nanodiamonds, which are 4-5 nm carbon nanoparticles, have also been employed to expand the alveolar ridge (Ozak 2013). The increased demand for cosmetic restorations has led to increased development of goods that are the same colour as teeth in recent years. Composite nanoparticle technology is one area of nanotechnology that is frequently applied in dentistry. Artificial nanocomposite teeth are more abrasion-resistant and stable than acrylic and composite micro fill teeth. Nanoparticles enable the manufacturing of composites with a smooth surface after the polishing stage and give the content exceptional aesthetic properties. Nanoparticles are used in order to increase aesthetics by increasing the transparency of surfaces and durability rate (Rattan 2021).

#### 4.16. APPLICATION IN NEUROLOGICAL DISORDERS

The Blood-Brain Barrier (BBB) protects the human brain, which is the body's most delicate and intricate organ.

The BBB can only pass-through lipophilic compounds or molecules with a molecular weight of 400–600 Da or less, leaving few alternatives for particular future medicinal and diagnostic procedures. Potentially given macromolecular medications are unable to pass through the endothelial capillaries in the brain, preventing them from reaching their CNS target. However, BBB may be resolved by nanoparticles and polymer coatings, enabling medication delivery to the CNS. Polymeric nanoparticles make up the bulk of drug delivery methods used to treat neurological illnesses because they have been shown to pass through tight cell junctions, bypass BBB, encapsulate more medication, and may be coupled with ligands to enable site-specific drug release. The most efficient option for brain medication administration appears to be polymeric nanoparticles like (butyl cyanoacrylate) (PBCA) or poly(isohexylcyanoacrylate) (PIHCA), poly (lactic acid) (PLA), or copolymer (lactide-co-glycolide) (PLGA), and human serum albumin (HSA). Iron oxide NPs may be tracked using MRI once they have entered these cells, such as macrophages. When determining the makeup of the BBB in various disorders defined by inflammation, can be incredibly helpful in monitoring macrophages (Dilnawaz 2015).

Parkinson's disease is characterized by the death of dopaminergic neurons in the substantia nigra and the build-up of  $\alpha$ -synuclein in the brain stem (PD). Using photoelectrochemical immunosensors, nanotube arrays with gold and titanium dioxide detect  $\alpha$ -synuclein. Additionally, when combined with anti- $\alpha$ -synuclein, polybutyl cyanoacrylate nanoparticles aided in the clearance of  $\alpha$ -synuclein from neurons (Ambesh 2015). As a result of gene transfer gene expression is altered in neurological disorders, particularly in degenerative illnesses like Alzheimer's and Parkinson's disease. This often increases the capacity of neuronal cells to regenerate and live on their own. In the process of gene transfer, nanoparticles can be employed instead of viral vectors. They are more efficient, simpler to produce, and they elicit a lesser immunological reaction. As gene and protein expression vectors, organically modified silica nanoparticles and nanoparticles coupled with chitosan and green fluorescent protein (pGFP) may be employed (Kanwar 2012). Engineered nanoparticles conjugated with drug moieties and imaging agents that have dimensions between 1 and 100 nm could potentially be used to ensure enhanced efficacy, cellular uptake, specific transport, and delivery of specific molecules to the brain, owing to their modified physico-chemical features. The conjugates of nanoparticles and medicinal plants, or their components known as nano phytomedicine, have been gaining significance lately in the development of novel neuro-therapeutics owing to their natural abundance, promising targeted delivery to the brain, and lesser potential to show adverse effects (Bhattacharya 2022).

## 5. LATEST STUDIES

The application of nanotechnology products in the medical field is increasing day by day as its application is making hectic work easier and handier with fewer side effects. The latest development in the medical field includes drug delivery through the nasal passage. The nasal epithelium has a large absorption surface, is highly vascularized, and permeable, and permits direct drug penetration into the systemic circulation without going via gastric or hepatic first-pass metabolism. The important anatomical feature offers a possible path for CNS medication delivery directly. When a medication is administered through the nasal cavity, it passes through the nasal mucosa into the systemic circulation and may or may not pass through the barriers and enter the CNS. Contrarily, the olfactory epithelium, olfactory neurons, and trigeminal nerves are important in the delivery of

drugs to the brain (Ji 2021).

The pathophysiological condition known as atherosclerosis is characterized by the spatial deposition of numerous substances, including lipoproteins (particularly cholesterol), immune cells (circulating monocytes), proinflammatory factors (macrophages and T-cells), degraded extracellular matrix components, and necrotic products, which significantly affect the medium and large arteries. In order to cure atherosclerosis, synthetic polymer-lipid hybridnanoparticles were created. Due to the integration of two dual-responsive nanomaterials, the spatially tailored hybrid nanomaterials specifically target several target areas. In addition, the highly engineered hybrid nanomaterials enabled the encapsulation of high SPR displaying inorganic nanoparticles (AuNPs, SPIONs, and QDs) as a possible contrast agent that facilitates bioimaging modalities. Hybrid nanomaterials may thus offer a fresh foundation for the diagnosis and treatment of atherosclerosis. Previously, iron oxide nanoparticles and prostacyclin were coupled with spatially tailored solid-lipid nanoparticles (SLN), which showed a reduction in platelet aggregation and may be useful for atherosclerosis theragnostic (Pala 2021).

## 6. CONCLUSION

Nanomaterials are a viable tool for the development of drugs, gene delivery, biomedical imaging, and diagnostic biosensors due to their enhanced surface area and nano-size effects. The distinctive size, shape, chemical composition, surface texture, charge, solubility, and aggregation of nanomaterials can substantially affect how they interact with biological molecules and cells. Due to its fusion with other technologies and the consequent birth of sophisticated and cutting-edge hybrid technologies, nanotechnology has a very bright future. Nanotechnology and biology-based technologies are interwoven. Nanotechnology is being utilized to control genetic material, while biological components are already employed to create nanomaterials. The capacity of nanotechnology to manipulate matter at the tiniest scale is transforming sectors including biotechnology, cognitive science, and information technology. It is also opening up new opportunities for collaboration across these and other fields. Nanotechnology can benefit every element of human existence with more research. Nutraceuticals, regenerative medicine, stem cell research, and medicine are some of the top fields that will be affected by advances in nanotechnology.

## REFERENCES

- Alaghmandfard, A.**, Sedighi, O., Rezaei, N. T., Abedini, A. A., Khachatourian, A. M., Toprak, M. S., & Seifalian, A. (2021). Recent advances in the modification of carbon-based quantum dots for biomedical applications. *Materials Science and Engineering: C*, 120, 111756.
- Ali, A.**, Zafar, H., Zia, M., ul Haq, I., Phull, A. R., Ali, J. S., & Hussain, A. (2016). Synthesis, characterization, applications, and challenges of iron oxide nanoparticles. *Nanotechnology, Science and Applications*, 49–67.
- Ambesh, P., & Angeli, D. G.** (2015). Nanotechnology in neurology: Genesis, current status, and future prospects. *Annals of Indian Academy of Neurology*, 18(4), 382–386.
- Anusiya, G., & Jaiganesh, R.** (2022). A review on fabrication methods of nanofibers and a special focus on application of cellulose nanofibers. *Carbohydrate Polymer Technologies and Applications*, 4, 100262.
- Basit, E.**, Shamsi, F., Kiyani, M., Ramzan, S., Ahmad, A., Khan, A., & Asiri, A. M. (2021). Nanomedicine: Promises and challenges. In *Nanomedicine Manufacturing and Applications* (pp. 109–123). Elsevier. DOI:10.1016/B978-0-12-820773-4.00016-0

- Bhattacharya, T.,** Soares, G. A. B. E., Chopra, H., Rahman, M. M., Hasan, Z., Swain, S. S., & Cavalu, S. (2022). Applications of phyto-nanotechnology for the treatment of neurodegenerative disorders. *Materials*, 15(3), 804.
- Bhushan, B.** (Ed.) (2017). *Springer handbook of nanotechnology*. Springer.
- Challa Kumar, C. S.** (2018). *Nanotechnology characterization tools for biosensing and medical diagnosis*. Springer Berlin Heidelberg.
- Chaturvedi, V. K.,** Singh, A., Singh, V. K., & Singh, M. P. (2019). Cancer nanotechnology: a new revolution for cancer diagnosis and therapy. *Current Drug Metabolism*, 20(6), 416–429.
- Chauhan, A. S.** (2018). Dendrimers for drug delivery. *Molecules*, 23(4), 938.
- Devulapally, R., & Paulmurugan, R.** (2014). Polymer nanoparticles for drug and small silencing RNA delivery to treat cancers of different phenotypes. *Nanomedicine and Nanobiotechnology*, 6(1), 40–60.
- Dilnawaz, F., & Sahoo, S. K.** (2015). Therapeutic approaches of magnetic nanoparticles for the central nervous system. *Drug Discovery Today*, 20, 1256–1264.
- El-Sayed, A., & Kamel, M.** (2020). Advances in nanomedical applications: diagnostic, therapeutic, immunization, and vaccine production. *Environmental Science and Pollution Research*, 27(16), 19200–19213.
- Fam, S. Y.,** Chee, C. F., Yong, C. Y., Ho, K. L., Mariatulqabtiah, A. R., & Tan, W. S. (2020). Stealth coating of nanoparticles in drug-delivery systems. *Nanomaterials*, 10(4), 787.
- Ghamsari, M. S.** (Ed.) (2018). *State of the Art in Nano-bioimaging*. IntechOpen.
- Gholami, A.,** Hashemi, S. A., Yousefi, K., Mousavi, S. M., Chiang, W. H., Ramakrishna, S., & Babapoor, A. (2020). 3D nanostructures for tissue engineering, cancer therapy, and gene delivery. *Journal of Nanomaterials*, 1–24.
- Grodzinski, P.,** Kircher, M., Goldberg, M., & Gabizon, A. (2019). Integrating nanotechnology into cancer care. *ACS Nano*, 13, 7370–7376.
- Gun'ko, Y. K.** (2016). Nanoparticles in bioimaging. *Nanomaterials*, 6(6), 105.
- He, X., & Ma, N.** (2014). An overview of recent advances in quantum dots for biomedical applications. *Colloids and Surfaces B: Biointerfaces*, 124(1), 118–131.
- Hulla, J. E., Sahu, S. C., & Hayes, A. W.** (2015). Nanotechnology: History and future. *Human & Experimental Toxicology*, 34(12), 1318–1321.
- Jackson, T. C., Patani, B. O., & Effiong, D. E.** (2017). Nanotechnology in Diagnosis: A Review. *Advances in Nanoparticles*, 6, 93–102.
- Ji, Y.,** Song, S., Li, X., Lv, R., Wu, L., Wang, H., & Cao, M. (2021). Facile fabrication of nanocarriers with yolk-shell mesoporous silica nanoparticles for effective drug delivery. *Journal of Drug Delivery Science and Technology*, 63, 102531.
- Jin, C.,** Wang, K., Oppong-Gyebi, A., & Hu, J. (2020). Application of nanotechnology in cancer diagnosis and therapy—a mini-review. *International Journal of Medical Sciences*, 17(18), 2964.
- Kanwar, J. R.,** et al. (2012). Nanoparticles in the treatment and diagnosis of neurological disorders. *Nanomedicine: Nanotechnology, Biology and Medicine*, 8(4), 399–414.
- Kargozar, S., & Mozafari, M.** (2018). Nanotechnology and Nanomedicine: Start small, think big. *Materials Today: Proceedings*, 5(7), 15492–15500.
- Makkithaya, K. N.,** Nadumane, S., Zhuo, G. Y., Chakrabarty, S., & Mazumder, N. (2022). Nanoparticle based collagen biomaterials for wound healing. In *Collagen Biomaterials*. IntechOpen.
- Mirza, A. Z., & Siddiqui, F. A.** (2014). Nanomedicine and drug delivery: a mini review. *International Nano Letters*, 4, 1–7.
- Momenimovahed, Z., & Salehiniya, H.** (2019). Epidemiological characteristics of and risk factors for breast cancer in the world. *Breast Cancer: Targets and Therapy*, 151–164.
- Moore, A. R.,** Rosenberg, S. C., McCormick, F., & Malek, S. (2020). RAS-targeted therapies: is the undruggable drugged? *Nature Reviews Drug Discovery*, 19(8), 533–552.
- Nene, A.,** Yu, X., Kaithal, P., Luo, H., Somani, P., & Ramakrishna, S. (2020). Magnetic Iron Oxide Nanoparticle (IONP) Synthesis to Applications: Present and Future. *Materials*, 13(20), 4644.
- Nikalje, A. P.** (2015). Nanotechnology and its applications in medicine. *Medicinal Chemistry*, 5(2), 081–089.
- Ozak, S. T., & Ozkan, P.** (2013). Nanotechnology and dentistry. *European Journal of Dentistry*, 7(1), 145–151.
- Pala, R.,** Pattnaik, S., Busi, S., & Nauli, S. M. (2021). Nanomaterials as novel cardiovascular theranostics. *Pharmaceutics*, 13(3), 348.
- Papakostas, D.,** Rancan, F., Sterry, W., Blume-Peytavi, U., & Vogt, A. (2011). Nanoparticles in dermatology. *Archives of Dermatological Research*, 303, 533–550.
- Pedziwiatr-Werbicka, E.,** et al. (2019). Dendrimers and hyperbranched structures for biomedical applications.

*European Polymer Journal*, 119, 61–73.

**Rattan, S.**, Fawcett, D., Tennant, M., Granich, J., & Poinern, G. E. J. (2021). Progress of nanomaterials in preventative and restorative dentistry. *Recent Progress in Materials*, 3(1). doi:10.21926/rpm.2101007

**Rizvi, S. A., & Saleh, A. M.** (2018). Applications of nanoparticle systems in drug delivery technology. *Saudi Pharmaceutical Journal*, 26(1), 64–70.

**Roco, M. C.** (2011). The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years. *Journal of Nanoparticle Research*, 13, 427–445.

**Sahu, T.**, et al. (2021). Nanotechnology based drug delivery system: Current strategies and emerging therapeutic potential. *Journal of Drug Delivery Science and Technology*, 63, 102487.

**Sarang, M. K., & Padhi, S.** (2016). Solid lipid nanoparticles – a review. *Journal of Critical Reviews*, 3(3), 5–12.

**Sarkar Siddique, & Chow, J. C. L.** (2020). Gold nanoparticles for drug delivery and cancer therapy. *Applied Sciences*, 10, 3824.

**Sathiyapriya, R.**, et al. (2019). Nanotechnology in materials and medical sciences. *International Journal of Advanced Science and Engineering*, 5(3), 1077–1084.

**Shin, M. D.**, et al. (2020). COVID-19 vaccine development and a potential nanomaterial path forward. *Nature Nanotechnology*, 15(8), 646–655.

**Shi, C.**, et al. (2020). Nanoscale technologies in highly sensitive diagnosis of cardiovascular diseases. *Frontiers in Bioengineering and Biotechnology*, 8, 531.

**Sim, S., & Wong, N. K.** (2021). Nanotechnology and its use in imaging and drug delivery. *Biomedical Reports*, 14(5), 1–9.

**Singla, S.**, et al. (2021). Photocatalytic water splitting hydrogen production via environmental benign carbon based nanomaterials. *International Journal of Hydrogen Energy*, 46(68), 33696–33717.

**Smart, E.**, et al. (2018). Chemotherapy drugs induce germ cell loss in an in vitro model of the prepubertal testis. *Scientific Reports*, 8(1), 1773.

**Soto, F.**, Wang, J., Ahmed, R., & Demirci, U. (2020). Medical micro/nanorobots in precision medicine. *Advanced Science*, 7(21), 2002203.

**Thomas, S. C.**, et al. (2015). Ceramic nanoparticles: Fabrication methods and applications in drug delivery. *Current Pharmaceutical Design*, 21, 6165–6188.

**Wang, C.**, et al. (2018). Prevalence and risk factors of chronic obstructive pulmonary disease in China. *The Lancet*, 391, 1706–1714.

**Yao, C. G., & Martins, P. N.** (2020). Nanotechnology applications in transplantation medicine. *Transplantation*, 104(4), 682–693.

**Yezdani, U.**, et al. (2018). Application of nanotechnology in diagnosis and treatment of various diseases. *World Journal of Pharmacy and Pharmaceutical Sciences*, 7(11), 1611–1633.

**Zhang, X.**, Cong, H., Yu, B., & Chen, Q. (2019). Recent advances of water-soluble fullerene derivatives in biomedical applications. *Mini-Reviews in Organic Chemistry*, 16(1), 92–99.

**Zhang, Y.**, Liu, Y., Liu, H., & Tang, W. H. (2019). Exosomes: Biogenesis, biologic function and clinical potential. *Cell & Bioscience*, 9, 1–18.

