Review Article

# Sustainable Nanotechnology: A Biocompatible Cutting-Edge Approach to Cancer Treatment

**Shashwat Pandey***

M-Pharm (Pharmaceutics), Department of Pharmaceutical Sciences, Babasaheb Bhimrao Ambedkar University, (A Central University) vidya vihar, Raebareli road, Lucknow,226025 Uttar Pradesh, India.

***Corresponding author's E-mail:** Shashwatpandey0510@gmail.com

**Received:** 16-06-2024; **Revised:** 28-09-2024; **Accepted:** 10-10-2024; **Published on:** 15-10-2024.

**ABSTRACT**

Green nanotechnology in cancer therapy refers to the use of environmentally friendly and sustainable nanomaterial and processes to diagnose, treat, and prevent cancer. Traditional cancer therapies often come with significant side effects and may harm the environment. Green nanotechnology aims to address these issues by developing sustainable and biocompatible solutions. One example of green nanotechnology in cancer therapy is the use of nanomaterials, such as nanoparticles, that can deliver drugs directly to cancer cells and thus biocompatible and non-toxic nanomaterials were developed for healthy cells, reducing the risk of side effects. Additionally, these nanoparticles can be engineered to specifically target cancer cells, improving the effectiveness of treatment. Green nanotechnology also incorporates eco-friendly manufacturing processes; by utilizing greener synthesis methods and reducing the reliance on hazardous chemicals, researchers strive to minimize the environmental impact of nanomaterial production. Green nanotechnology researchers explore innovative approaches to cancer therapy, such as using nanomaterial to enhance imaging techniques or developing nanoparticles that can detect and remove cancer cells more efficiently. Green nanotechnology in cancer therapy focuses on developing sustainable and environmentally friendly approaches to diagnose, treat, and prevent cancer. By utilizing biocompatible nanomaterial and eco-friendly manufacturing processes, researchers aim to improve cancer treatments while reducing their impact on the environment.

**Keywords:** Green Nanotechnology, Cancer therapy, Nanoparticles, Green Chemistry, Biomimetics, Microbes.

## 1. INTRODUCTION

### Green nanotechnology

A recent initiative known as "green nanotechnology" seeks to replace current products with current, environmentally friendly nanoproducts that are more persistent lifetimes by utilizing nature's ability to eliminate or the reduction of hazards involved with utilization of nanomaterials that simulate the well-being of the humans along with the nature [1,2]. Utilizing fewer resources and renewable inputs whenever possible, minimizes the use of fuel and energy. Additionally, by minimizing raw materials, energy, and water in conjunction with the reduction in greenhouse emissions and hazardous waste, the goods, processes, and applications were likely to provide ample matches toward natures protection. The key benefits of green nanotechnology are decreased consumption of non-renewable raw resources, less waste and increased energy efficiency. Green nanoscale technology presents an incredible opportunity to avoid negative consequences before they arise [3,4] and thus, they are considered to be as bioengineering, nanofabrication, nanobiotechnology, optical engineering and medicines.

Additionally, Eco-friendly chemistry and Eco-engineering are combined to develop clean nano scale technology. Green chemistry and green engineering are thus important considerations for the main interest in green nanotechnology [5] and **Table 1** and **Table 2** depicts the principles involved in it.

**Table 1:** Principle of Eco-Conscious Chemistry[5]

| Sr. No | Principle |
|---|---|
| 1 | Prevention: It is better to prevent waste than to treat or clean up waste after it has been created. |
| 2 | Atom economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product |
| 3 | Less hazardous chemical syntheses: Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment. |
| 4 | Designing safer chemicals: Chemical products should be designed to affect their desired function while minimizing their toxicity. |
| 5 | Safer solvents and auxiliaries: The use of auxiliary substances (e.g., solvents, separation agents, and others) should be made unnecessary wherever possible and innocuous when used. |
| 6 | Design for energy efficiency: Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure. |
| 7 | Use of renewable feedstock's: A raw material or feedstock should be renewable rather than |

| | |
|---|---|
| | depleting whenever technically and economically practicable. |
| 8 | Reduce derivatives: Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible because such steps require additional reagents and can generate waste. |
| 9 | Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents. |
| 10 | Design for degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment. |
| 11 | Real-time analysis for pollution prevention: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances. |
| 12 | Inherently safer chemistry for accident prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires |

**Table 2:** Principle of Eco-Conscious Chemistry Engineering[6]

| Sr. No | Principle of Green Technology |
|---|---|
| 1 | Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools |
| 2 | Conserve and improve natural ecosystems while protecting human health and well-being |
| 3 | Use life-cycle thinking in all engineering activities |
| 4 | Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible |
| 5 | Minimize depletion of natural resources. |
| 6 | Strive to prevent waste |
| 7 | Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures. |
| 8 | Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability |
| 9 | Actively engage communities and stakeholders in the development of engineering solutions |

## 2. Green nanoparticles for Drug Delivery

### 2.1 Nanoparticles in Drug Delivery

These are the agents with a size range in between 1-100µm and possess specific characteristics such as enhanced stability, robustness, affordability, biocompatibility, specific targeting, etc. The primary cause of the significant differences in their physiochemical properties of the nanoparticles (NPs) is along with minute dimensions and elevated ratio in surface-to-volume ratio [6,7]. The Eco-Conscious Chemical Principles are taken into consideration while developing nanoparticles in an environmentally friendly manner [6]. The green synthesis uses simple, affordable, environmentally safe, and easily accessible raw materials; the process involves fewer steps and no hazardous chemicals or noxious by-products formed [8].

**a) Liposome**

The very first drug delivery system that was studied was liposomes. They are colloidal or nano, micro-particular carriers, typically ranging in size from 80 to 300 nm [9] these discrete particles comprised of bilayers along with other surfactants, and phospholipids and steroids (like cholesterol). They develop spontaneously when certain lipids diffuse in aqueous environments, and this is how liposomes are generated, especially by sonication [10].

**Function: -**

- It has been found that liposomes enhance the drug's solubility.
- Enhance their pharmacokinetic attributes, including the chemotherapeutic agent's therapeutic index, rapid metabolism and reduction in undesirable side effects with an increase in anti-cancer efficacy both *in vitro and in vivo* [11].
- Increases the residence time and duration of the action of such particles as their number decreases.
- Liposomes cell induce lipid transfer, adsorption, fusion and endocytosis. Numerous examples including antitumor drugs [11], Neuro-signaling Molecules (5-HT (5-hydroxytryptamine)) [12], Antimicrobial Drugs [13,14], Inflammatory Suppressants [15], and Disease-Modifying Antirheumatic Drugs [16], is found in liposomal formulations.

**b) Nanoparticles based on solid lipids**

Solid lipids form a scaffold at body temperature and is the basis for several types of carrier systems, including Lipid-based Nanoparticles, Enhanced Lipid Nanoparticles, Lipid-bound Drug Complexes [17]. For cutaneous [18], peroral [19], parenteral [20], ocular [21], pulmonary [22], and rectal [23] administration, they have been used.

Particles composed of crystalline lipids, such as Fractionated triglycerides, Multifunctional glycerides or surface-active agents, are known as solid lipid nanoparticles [24].

The following are the primary characteristics of solid lipid nanoparticles:

- Good physical stability and protecting incorporated drugs against deteriorating
- Regulated release of drugs

- High tolerance [25,26].

**c) Polymeric nanoparticles (PNP)**

Structures having a diameter ranging from 10 to 100 nm are known as polymeric nanoparticles. The primary source of them is synthetic polymers such as: -

- Poly- -poly-caprolactone [27]
- Polyacrylamide [28]
- Polyacrylate [29]

When obtained as Natural polymers, e.g., albumin [30], DNA, chitosan [31, 32] gelatin [33] PNPs can be categorized into biodegradable types, such as poly(L-lactide) (PLA) [34], and polyglycolide (PGA)) [35] and non-biodegradable types, such as polyurethane) [36]. During the polymerization stage, drugs can wrap themselves on the PNP structure [37] or become immobilized on the PNP surface following a polymerization reaction [38]. In addition, drugs may be delivered into the target tissue by desorption, diffusion, or erosion of nanoparticles [39].

**d) Dendrimer nanocarriers**

These are the special polymers with distinct size and structures called dendrimers. Among all the biological systems dendritic design is believed to have a familiar design. Examples of construction of dendritic nanometric molecule possess proteoglycans, glycogen, and amylopectin [40]. While the symmetrical dendrimer has a distinct architecture opposed to that of a linear polymer and thus respective elements were illustrated as-

- Kernel
- Dendron's (repeated units that create a highly branched, three-dimensional architecture.
- surfactants, molecules.

Atom or a molecule are tending to interact with Dendron and thus they are termed as core assuming that it possesses two similar functional groups. The monomer molecules known as dendrons, or dendrimer arms, are connected to the core and form layers, building subsequent generations (albeit their growth is restricted in space). Dendrimer physicochemical properties along with confirmation of biocompatibility with surface functional group [41]. Dendrimers like Poly (amido amide) (PAMAM) are widely utilized in biological applications. The arrangement of Polyamidoamine dendrimers and the binding of active drugs [42] or chromosomal part [43] into these molecules. For example: Cisplatin is the drug immobilized in PAMAM dendrimer. When compared to free cisplatin, this complex has a number of benefits, including the emission of a drug at lower rate with the piling of greater amount of drug in solid tumors, and less toxicity across the board [44,45].

**e) Silica Materials**

The two types of silica materials employed in controlled drug delivery systems are mesoporous silica nanoparticles and xerogels [46]. Silicates crystals are very prominent as inorganic that tend to be chosen for biological applications [47]. Silica xerogels have a large surface area, high porosity, and an amorphous structure. Synthesis parameters determine the form and size of a porous structure [48]. The technique of sol-gel is widely applied in the production of drug-loaded silica gels. The characteristics of xerogels employed in controlled drug release may be altered by modulating the catalyst concentration, temperature, reagent ratio, and drying pressure throughout the synthesis process [49, 50]. Phenytoin [51], doxorubicin [52], cisplatin [53], and metronidazole [54] and so they are few instances of drugs that have been placed into xerogels by this method. Mesoporous silica nanomaterials come in two most popular forms: SBA-15, which has a well-ordered, linked system of pores in the shape of a hexagon, and MCM-41, which has a hexagonal arrangement of mesopores [55]. Chemical or physical adsorption is the method by which drugs are loaded into mesoporous silica material [56]. During these procedures, an array of drugs, such as drugs for cancer treatment[57, 58] and active molecules for the irregular rhythmicity of heart [59], were incorporated into MNSs and the emissivity of active molecule can be controlled by diffusion.

**f) Carbon nanomaterials**

Drug delivery techniques use nanotubes and nanohorns, two different forms of carbon nanocarriers. The distinctive architecture of carbon nanotubes is formed by rolling graphite layers into unilayer carbon nanotubes or multi-layer carbon nanotubes with elevated surface area that possess conductivity with electrical and thermal property [60] chemically altering the superficial layer of nanotubes can increase their biocompatibility [61]. Covalent linkage of PAMAM dendrimers [62], amphiphilic di block copolymers [63], or PEG layers [64] on the surface of CNTs or their dispersion inside a hyaluronic acid matrix [65] can all be used to carry out this adaptation. Due to their mechanical because of their mechanical, SWCNTs have been utilized for the betterment of the qualities of other carriers like polymeric or non-polymeric composites [66].

There are three approaches to immobilize medicines in carbon Nano carriers:

- Active drug molecule incorporated drug in a carbon nanotube [67].
- Surface adsorption (via hydrogen bonding, hydrophobic, electrostatic, and other interactions) on the surface or in the gaps between the nanotubes[68,69].

Coupling of functionalized carbon nanotubes (f-CNTs) with active substances. Compared to the other two approaches, encapsulation offers the benefit of shielding the drug from degradation during cell transit and releasing it under particular conditions [70]. Chemical or electrical control can be used to regulate the release of drugs from carbon nanotubes. To prevent unexpected medicine release, the open ends of carbon nanotubes (CNTs) were sealed with

polypyrrole sheets [71]. The selectivity of drug delivery systems was further enhanced by the addition of binding agents, such as folic acid and epidermal growth factor [72, 73]. The only single-wall nanotubes known to exist, called Nano horns, have characteristics with nanotubes [74]. They are very pure and conveniently made at a very low cost since their creation procedure does not require a metal catalyst.

**g) Magnetic nanoparticles (MNPs)**

Multiple characteristics of magnetic nanomaterial extends them to very high selectivity. These include, in particular being simple to manage with the help of an external magnetic field; being able to visualize (drug delivery strategies can be passive or active); and having improved target tissue absorption leading to Effective therapy at doses that are therapeutically ideal [75].

However, difficulties in achieving these objectives appear in the majority of situations involving the employment of magnetic nanocarriers. It is most likely related to an inadequate magnetic system or improper magnetic nanoparticle attributes.

MNPs may be classified as pure metals (cobalt [76], nickel [77], manganese [78], ferrous [79], alloys, and magnetic oxides based on their spin orientation properties. However, the selection of magnetic material is extremely restricted when restricting the applications of MNPs to biomedicine exclusively. The reason for this restriction is ignorance of the harmful impact that most of these nanomaterials have on human health. Because of their advantageous characteristics, iron oxide nanoparticles are the only kind of MNPs that the FDA has approved for clinical usage. A single step can be easily synthesized utilizing an alkaline co-precipitation method between $Fe^{2+}$ and $Fe^{3+}$, and the chemical stability of the product under physiological conditions can be altered by coating it with different substances [80]. Different shells, such as golden [81], polymeric [82], and silane [83]. Furthermore, the human liver, spleen, and heart all naturally contain iron oxides, notably magnetite and maghemite [84], indicating their biocompatibility and lack of toxicity at physiological concentrations. Determining a safe maximum level of MNPs for use in biomedicine is essential [85].

**2.2 Method of Green Nanoparticle Synthesis.**

Research in these relatively fresh and largely uncharted territories has been sparked by the biosynthesis of nanomaterials[86]. At the nano- and micro-length scales, nature has evolved a number of methods for the synthesis of inorganic materials[87]. Bio-organism synthesis is compatible with notions of green chemistry. As "green synthesis" of nanoparticles uses safe, non-toxic, and environmentally acceptable chemicals, several eco-friendly procedures are used to synthesize nanoparticles[88].

These strategies include:

- Plant-derived nanoparticle
- Microbial-derived nanoparticle

**2.2.1 Plant-derived Nanoparticles**

Metallic nanoparticles induce their effect in various forms and sizes for use in biological systems, various plant components, organic and inorganic are utilized. Changes in the quantity of plant extract in the reaction medium and the use of a variety of metal concentrations can modify biosynthesis processes, changing the shape and size of NP [89]. Ex: Green tea (zeta potential: 26.52 mV at pH 7) can be used to perform the infusion-dialysis method for separating tea NPs (spherical, 100–300 nm). Furthermore, they found that spherical tea NPs could serve as multipurpose carriers for cancer treatment in vitro [90].

**Preparation of Tea Nanoparticles (TNPs)**

***Applications of plant-derived nanoparticles***

When it comes to producing useful nanoparticles and nanostructures with nontoxic and biocompatible qualities, plants can serve as a renewable, diverse, and sustainable source along with a platform. Thus, the application of plants in Nano biotechnology, sometimes referred to as "green nanotechnology," continues to grow swiftly.

**Table 3:** Applications of plant-derived nanoparticles

| Plant derived Nano particles | Application |
|---|---|
| **Protein-based** | • Controlled drug and gene delivery<br>• Bioactive compound delivery<br>• Tissue engineering<br>• Food industry<br>• Improvement of oral bioavailability of drugs<br>• Drug-loaded carriers for medical applications (e.g., gliadin) |
| **Polysaccharide-based** | Drug delivery systems based on nitrocellulose, Drug excipients, Blood vessel replacement, Soft-tissue-ligament, meniscus, and cartilage replacements, Nucleus pulposus replacement Tissue repair, regeneration, and healing |
| **Adhesive based** | Tissue engineering and biomedical applications, Platelet aggregation leading to clotting and the sealing of wounds, Cosmetics |
| **Lipid-based** | Generation of soft nanomaterials, such as nanotubes, nanofibers, gels, and surfactants, Biomedical applications |

Numerous fields, including photonics, medication and gene delivery, solar cell devices, biomedicine, biosensors, electronics, sensing, environmental remediation, bio imaging, and biomaterials, have made use of plant-issued nanostructures and so due to this reason **Table 3** depicts the applications associated with the involvement of plant-derived nanoparticle [91].

### 2.2.2 Microbial-derived nanoparticle

Upon multiple studies it has been detected that siliceous agents were synthesizes via diatoms [92], gypsum and calcium layers and thus they are generated by S-layer bacteria [93], and magnetite particles are synthesized by magneto tactic bacteria [94, 95]. Microbes are thought to be powerful, environmentally friendly green nano factories that synthesize nanoparticles. Studies on the A potential field of research in nanobiotechnology that bridges the gap across biotechnology and nanotechnology is the microbial production of nanoparticles. Interactions between metals and bacteria have been used in a variety of biological applications in the fields of bioremediation, bio mineralization, bioleaching, and bio corrosion [96].

#### I. Biosynthesis of nanoparticles by bacteria

Microbes synthesize nanoscale inorganic chemicals within and outside their cells. The primary cause of microbial resistance to heavy metals lies in energy-dependent ion pumping by membrane proteins functioning as ATPase, chemiosmotic cation transporters, or proton anti-transporters along with chemical detoxification mechanisms. Microbial resistance as well is influenced by differences in solubility [97,98]. Thus, microbial systems can reverse the toxicity of the metal ions by transiting soluble harmful inorganic ions to insoluble non-toxic metal nanoaggregates. Microbial purification can be executed by two different techniques: extracellular bio mineralization, bio sorption, complexation, or precipitation, and intracellular bioaccumulation. Metal nanoparticles yield extracellularly possess multiple marketed claims around plentiful zones. Since polydispersity is the foremost root of priority, it is very important to upgrade the state for monodispersity in a biological procedure [99]. Particles that accumulate within the cell have a specific size and decreased polydispersity.

#### a) Intracellular synthesis of nanoparticles by bacteria

Supplementary pace seeks to emit the intracellularly prorogated nanoparticles tend to incorporate ultrasonic analysis or in contact with appropriate detergents. This might be applied to mining wastes and metal leachates to recover precious metals. Furthermore, a variety of chemical processes may employ bio-matrixed metal nanoparticles as catalysts [100]. By doing this, the nanoparticles will be better preserved for ongoing use in bioreactors.

The deposition of mineral ores has been associated with bacterial activity for several years: -

- According to recent reports, gold may be accumulated by pedomicrobium-like budding bacteria during the iron and manganese oxide deposition stage of the Alaskan placer [101].
- Water-soluble Bacillus subtilis 168 altered $Au^{+3}$ ions inside the cell walls to $Au^{+1}$, creating an octahedral structure that measured 5–25 nm [102-103].
- Gold mine-enriched heterotrophic sulfate-reducing bacteria (SRB) destabilized the gold(I)-thiosulfate complex $Au(S_2O_3)$ to elemental gold in the bacterial membrane, releasing $H_2S$ as a final byproduct of metabolism [104]. Within the periplasm of the Fe (III) reducing bacterium Geobacter ferrireducens, gold was precipitated intracellularly [105]. Under anaerobic circumstances and with hydrogen gas present, Shewanella algae reduced $Au^{+3}$ ions at 25 °C with 10–20 nm in the periplasmic space (pH 7.0) and with 15–200 nm on the surfaces of mesophilic bacterial resting cells that reduced iron (III). (pH 2.8) [106].
- The photosynthetic bacteria Rhodobacter capsulatus was also demonstrated to possess the ability to reduce trivalent aurum, demonstrating 92.43 mg $[Hg(AuCl_4)]$/ g dry weight as the biosorption capacity during the logarithmic development phase. Carotenoids and NADPH-dependent enzymes released extracellularly and/or incorporated in the membrane were shown to enhance the biosorption and bioreduction of $Au^{+3}$ to $Au^{+2}$ in extracellular and plasma membranes [107].

#### b) Extracellular synthesis of nanoparticles by bacteria

The microbial synthesis of metal nanoparticles relies upon the position of the declining agents within the cell. When soluble secretory enzymes or cell wall reductive enzymes are engaged in the declining technique of metal ions, metal nanoparticles are determined extracellularly. Extracellular yield of nanoparticles has an expensive range of solicitation in optoelectronics, electronics, bioimaging, and sensor technologies than intracellular aggregation does. At room temperature, it was discovered that RhodoPseudomonas encapsulates a prokaryotic bacterium that reduces Au+3 to $Au^0$ [108]. According to the TEM examination, at pH 7.0, the greater part of the particles was spherical and lie in-between 10 and 20 nm in size. However, the pH of the solution changed, different forms and sizes emerged. Together with spherical nanoparticles, triangular nanoparticles also materialized at pH 4.0. These nanoparticles were spherical and possess a diameter in-between 10 and 50 nm, and triangular size range in between 50 and 400 nm. There was also a study on the elevation of state for the synthesis of anisotropic gold nanostructures with altering gold ion concentrations [109] here; a reduced concentration of gold ions was merged to a cell-free constituents of R. capsulata to create specific Au nanoparticle having diameter 10 – 20nm. However, more gold ions were used in the synthesis of densely networked structures of 50–60 nm gold nanowires. The bio reduction and capping of the gold nanoparticles were shown to be facilitated by one or more proteins, with sizes ranging from 14 to 98 kDa, according to analysis performed using sodium

dodecyl sulfate-polyacrylamide gel electrophoretic (SDS-PAGE).

### II. Virus-mediated biosynthesis of nanoparticles

Amino acids, polyphates, and fatty acids are examples of biological molecules that are utilized as templates in the formation of semiconductor nanocrystals. Specifically, the morphologies of semiconductors nanocrystals derived by altering the composition and concentration of various fatty acids (chain lengths) [110,111]. There are further biological techniques that can be used to synthesize inorganic compounds in an environmentally responsible manner. Inorganic nanoparticle and microstructure synthesis via template-mediated methods has been achieved by the use of biological genetic material [112-114], peptides cages [115], lipid cylinders [116-117], viroin capsid capsules [118], bacterial exosomes [119], Smooth capsid layers [120], and multicellular superstructures [121].

Interestingly, the oxidative hydrolysis, sol-gel condensation, and co-crystallization of CdS and PbS processes that yield iron oxides were all modeled after the tobacco mosaic virus (TMV). It was made possible by external glutamate and aspartate functionalities present on the virus outer surface[122]. Self-assembled synthesizes their assembly, were used as biological templates to manufacture quantum dot nanowires. The crystalline capsid of the virus, M13 bacteriophages, produced peptides such as A7 and J140, which are capable of nucleating Cd-S and Zn-S. After being chosen via a pIII phage display, these ordered template peptides (A7/J140-pVIIIM13) were exposed to semiconductor precursor solutions. It was discovered that Cadmium-S entangled as nanowires of 3-5 nm or Zinc-S nanocrystals of hexagonal wurtzite, measuring around 5 nm, were constructed on the viral capsid. Using bi functional peptide virus A7 and J140 within the same viral capsid were synthesized, hybrid nanowires (ZnS–CdS) were produced.

### 2.3. Green Chemistry Principles

“The idea of "green chemistry" refers to "the architecture of chemical agents and the technique to obstruct or exclude the practice and design of precarious agents.” [123,124] The aim of the Green Chemistry technique is to achieve molecular sustainability through the integration of the design idea. Design is not an accident; rather, it is a reflection of human intention. It is composed of creativity, strategy, and precise conception. The purpose of the "design rules" called the purpose of exclusive authenticate guidelines of eco chemistry is to assist scientists intentionally work toward sustainability. "Green chemistry" is the technique of accurate plotting molecular methods and chemical synthesis to prevent negative effects [125].

**Framework of Green Chemistry**

The listed consideration of Green Chemistry is marked as:

- Plans executing Green Chemistry encircle development of the chemical life cycle.
- Green chemistry mainly eyes to decline innate hazards by devising chemical products and processes with reduced innate risk.
- Green Chemistry mainly exercise its responsibilities as a merged set of guidelines or standards for the plan

The supreme aim of green chemistry is to decline risk at every pace of the life cycle, which is also financially beneficial. Anything that poses a risk to people or the environment is considered a hazard. It is possible to prevent the inherent hazards associated with each stage of a chemical process, such as toxicity and physical risks like flammability and explosions, as well as global concerns like stratospheric ozone depletion. Depending on these risks, the type of starting material and primal matter used in chemical transitions along with the finished products synthesized, may provide dangers. When the Twelve Principles are combined into a single, cohesive framework, intrinsic hazards in chemicals and processes are reduced or eliminated.

Risk=f (hazard x exposure)

Where Risk determine hazard and exposure

**The Twelve Principles**

John Warner and Paul Anastas presented the Twelve Principles of Green Chemistry in 1998. They are included in **Table 1** because they provide a foundation for creating novel chemical products and procedures. Every aspect of the process life-cycle is covered by this framework, including the raw materials utilization, the efficacy and the preventive transition, and the pathogenicity and biodegradability of the finished products and reagents.

### 2.4. Characterization techniques

Various characterization difficulties with the nanoparticles impact the thorough and suitable characterization of the nanoparticles. Therefore, it is crucial to comprehend the issues encountered while characterizing nanoparticles and to choose an appropriate characterization method. In particular, the characterization of nanoparticles is done to evaluate the properties of the nanocomposite materials, including shape, size, crystallinity, fractal dimensions, orientation, zeta potential, wettability, solubility, particle size distribution, aggregation, hydrated surface analysis, and the intercalation and dispersion of nanoparticles and nanotubes, dictate their functionality. Along with the determination of many other techniques and so they are marked in **Table 4.**

**Table 4:** Characterization method for nanoparticles

| Type | Technique | Specific purpose | Reference |
|---|---|---|---|
| Formation of nanoparticle | UV spectrophotometry | Provides insights about the aggregation, stability, size, and structure of nanoparticles. | 126,127 |
| Morphology and particle size | Transmission electron microscopy | Determine the nanoparticles' morphology, size ($10^{-10}$ m), shape, and allographic structure. | 128,129 |
| | High-resolution transmission electron microscopy | Determine the atomic arrangement and local microstructures of crystalline nanoparticles, including the surface atomic arrangement, glide plane, lattice vacancies and defects, screw axis, and lattice fringe. | 130,131 |
| | Scanning electron microscopy | Evaluate the morphology directly by visual. | 132-134 |
| | Atomic force microscopy | Determine the dimensions (height, breadth, and length) as well as other physical characteristics (surface texture and morphology). | 128,135 |
| | Dynamic Light Scattering | Determine the distribution of particle size. | 135,133,136 |
| Surface charge | Zeta potential | Determine the characteristics of colloidal nanoparticles' stability and surface charge as well as the composition of the components that are coated on or encapsulated inside the particles. | 137 |
| | Fourier transform infrared spectroscopy | Evaluate the nanoparticles' functional groups to determine if a solid, liquid, or gas is emitting, absorbing, photoconductive, or scattering Raman light. | 138,139,133 |
| | X-ray photoelectron spectroscopy | Determine the structure and the speciation process of the various elements contained in the magnetic nanoparticles' chemical composition, as well as the mechanism of the reaction that takes place on their surface and the characteristics involved in the bonding of the various elements. | 139 |
| | Thermal gravitometric analysis | Evaluate the formation of coatings, such as polymers or surfactants, to assess the effectiveness of binding to the surface of magnetic nanoparticles. | 139 |
| Crystallinity | X-ray diffraction | Determine and measure various crystalline shapes or elemental composition of the nanoparticles. | 135,127,141 |
| Magnetic properties | Vibrating sample magnetometry | Assess magnetic nanoparticles' degree of magnetization. | 139 |
| | Superconducting quantum interference device magnetometry | Figure out the magnetic characteristics of the magnetic nanoparticles. | 139 |
| Other techniques used in nanotechnology | Chromatography and related techniques | Arrange the nanoparticles according to how appropriate they are for the mobile phase. | 141,142 143,144 |
| | Energy-dispersive X-ray spectra | Evaluate the nanoparticles' elemental composition. | |
| | Field flow floatation | Use magnetic susceptibility to distinguish between various nanoparticles. | 145 |
| | Filtration and centrifugation technique | Separate the nanoparticles' preparatory size into fractions. | 146-148 |
| | Hyperspectral imaging | Evaluate the various types of nanoparticles to examine their interactions and changes in water samples, and describe the functional groups and unique surface chemistry of the nanomaterial. | 149 |
| | Laser-induced breakdown detection | Examine the concentration and dimensions of the colloids. | 150,151 |
| | Mass spectrometry | Examine nanoparticles with fluorescent labels. | |
| | Small and X-ray scattering | Examine solid and liquid materials' structural characterization in the nanoscale range. | 152,153 |
| | X-ray fluorescence spectroscopy | Determine what elements are present in the samples whether they're liquid, powdered, or solid, and at what concentrations. | 141,142 |

### 2.5. Applications in Targeted Drug Delivery

The successful development of drug delivery systems based on organic, inorganic, and hybrid nanoparticles as drug carriers for active targeting, especially in chemotherapy and so there are a wide range of applications associated with it and thus they are marked in **Table 5.**

**Table 5:** Application of Green nanoparticles

| Application | Material | Purpose |
|---|---|---|
| Cancer therapy | Poly (alkyl cyanoacrylate) nanoparticles with anti-cancer agents, oligonucleotides | Targeting, reducing toxicity, enhanced uptake of anti-tumour agents, improved invitro and in vivo stability |
| Intracellular targeting | Poly (alkyl cyanoacrylate) polyester nanoparticles with anti-parasitic or anti-viral agents | Target reticuloendothelial intercellular infections |
| Prolonged systemic circulation | Poly esters with adsorbed polyethene glycols or pluronic | Prolonged systemic drug effect, avoid uptake by the reticuloendothelial system |
| Vaccine adjuvant | Poly (methyl methacrylate) nanoparticles with vaccines (oral and IM immunization) | Enhanced immune response alternate acceptable adjuvant |
| Per oral absorption | Poly (methyl methacrylate) nanoparticles with proteins and therapeutic agents | Enhanced bioavailability protection from GIT enzymes |
| Ocular delivery | Poly (methyl methacrylate) nanoparticles with steroids, anti-inflammatory agents, anti-bacterial agents for glaucoma | Improved retention of drug/ reduced washout |
| Oligonucleotide delivery | Alginate nanoparticles, poly (D,L –lactic acid) nanoparticles | Enhanced delivery of oligonucleotides |
| DNA delivery | DNA- gelatin nanoparticles, DNA- chitosan nanoparticles | Enhanced delivery and significantly higher expression levels |
| Other applications | Poly (alkyl cyanoacrylate) nanoparticles with peptides Poly(alkyl cyanoacrylate) nanoparticles, nanoparticles with adsorbed enzymes, nanoparticles with radioactive or contrast, copolymerized peptide nanoparticles of activated peptides | Crosses blood-brain barrier, immunoassays, improved absorption and permeation for transdermal applications, enzyme immunoassays, radio imaging agents, oral delivery of peptides |

## 3.Bio-inspired Nanomaterials in cancer therapy

### 3.1 Biomimicry in Nanotechnology

Biomimicry is the technique of developing new technologies with the required functionality by mimicking the characteristics, structures, and patterns seen in nature. Furthermore, the term was initially used in the 1950s by American biophysicist Otto Schimt [155,156].

This is a relatively young multidisciplinary topic that finds applications at almost all engineering scales, ranging from microscopic to enormous. The idea of mimicking nature is used in many fields of study and engineering to solve difficult problems. Still, engineered biomimicry encompasses three methodologies:

- Bio inspiration: Use of an idea from nature without changing its composition or method.
- Biomimetic: Replicating the real process to attain certain functionality [157.]
- Bio replication: Direct replication of a biological structure to achieve a certain functionality [158].

Researchers may utilize nanotechnology to investigate objects at the nanoscale, whereas biomimicry allows researchers to address issues using natural solutions. Working with matter at the nanoscale (10–9 mm) level is known as nanotechnology. Undoubtedly one of the most fascinating scientific breakthroughs of the 21st century, it has allowed for the creation of several amazing innovations, such as Nano sensors and Nano robots. Biomimicry and nanotechnology are closely connected subjects. Because all biological systems consist of units only visible at the nanoscale, biology is a source of inspiration for the creation of new instruments and systems that enhance the capabilities of technology already in use. Thus, the integration of nanotechnology with biomimicry is essential for the progress of science and technology [113]. Furthermore, biomimicry combined with nanotechnology is crucial for MEMS (microelectromechanical systems) and NEMS (nanoelectromechanical systems). Biomimetic NEMS are widely used in medicine [159].

Poly (lactic-co-glycolic acid) (PLGA) nanoparticles covered with cell membranes are an example of novel functional biomimetic nanoparticles have been created using natural

biological macromolecules as ingredients [160] and thus it is depicted in **Figure 1**, they are made from platelet membranes, nucleated cells such as neutrophils and macrophages, and cancer cells.

### 3.2. Methods of preparation

A biomimetic membrane that has been coated with a material or a biomimetic membrane that acts as a drug delivery vehicle combines to form biomimetic nanoparticles. **Table 6** represents an overview and a pertinent example of the many methods by which biomimetic nanoparticles might be produced. **Table 6:** Synthetic approaches for Green biomimetic nanoparticles for cancer therapy.

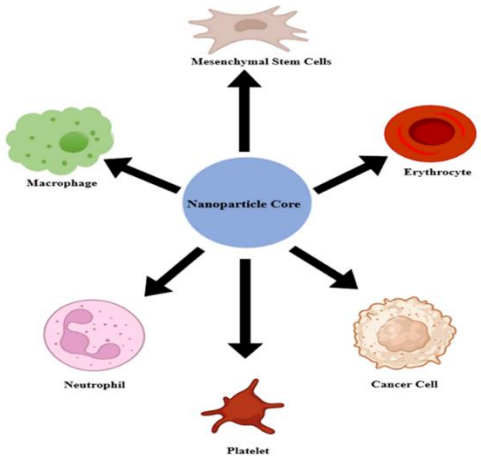


**Figure 1:** Biomimetic nanoparticles are made using a variety of naturally occurring biological macromolecules

**Table 6:** Synthetic approaches for Green biomimetic nanoparticles for cancer therapy.

| Method of preparation | Cell membrane coating | Core material | Application | Reference |
|---|---|---|---|---|
| Sonication | Erythrocyte<br>Cancer Cell<br>Stem Cell | PLGA<br>PLGA<br>$Fe_3O_4$ | Treatment of solid tumors.<br>Treatment of hepatocellular carcinoma.<br>Magnetic hyperthermia-mediated cell death. | 161<br>162<br>163 |
| Microfluidic sonication | Exosome | PLGA | Targeted therapy of homologous tumours by evasion of immune system. | 164 |
| Extrusion | Erythrocyte<br>Cancer cell-extracellular vesicles<br>Erythrocyte Albumin<br>Macrophage | $Ag_2S$ Quantum Dot<br>Gold<br>Albumin<br>Liposome | Sonodynamic therapy of tumours guided by fluorescence imaging.<br>Anti-cancer drug delivery Controlled release of ATP in cancer therapy.<br>Targeted anti-cancer therapy.<br>Targeted anti-cancer therapy | 165<br>166<br>167<br>168 |
| Sonication & extrusion | Platelet | Chitosan oligosaccharide-PLGA copolymer | Targeted anti-cancer therapy. | 169 |
| Microfluidic electroporation | Erythrocyte | $Fe_3O_4$ | Magnetic resonance imaging & photothermal therapy. | 170 |

**Role of Biomimetic in Cancer Cell Membrane Coating**

One of the most well-known biomimetic strategies for oncological applications is the coating of cancer cells and they are used to produce immortal cancer cells. Consequently, the immune-evading characteristics and extended blood circulation durations of cancer cell membrane coatings in biomimetic nanotechnologies and so they believed to be as a great option for the delivery of drugs. However, homotypic targeting—a feature of cancer cell membrane coatings allows these structures to connect to and detect the parent cancer cells by molecular means [171,172]. The only restriction is that the matching biomimetic structure can only attack tumors that originated from a particular kind of cancer cell [173]**.** Otherwise, any cancer cell type may be utilized to effectively produce cancer cell membranes. Homotypic targeting is made attainable by the molecules that bind cells to cells on the surface of cancer cells [172] and thus the ability of these biomimetic constructions developed from cancer cells to identify and bind to both primary and metastatic tumors is primarily linked to the general process of homotypic targeting. and thus, it is depicted in **Figure 2**.

On the other hand, uncoated nanoparticles that have been encapsulated with cancer cell membranes frequently offer more tumor-selective accumulation, reduced accumulation in healthy tissue, and molecular selectivity towards cancer

cells [171]. Cancer cell membrane coatings were used in the development of therapeutic medications, such as paclitaxel with doxorubicin to treat breast, ovarian, lung, and several other cancers [171,174,175]. Other nanoparticles, including poly (lactic-co-glycolic acid) (PLGA), indocyanine green-poly(lactic-co-glycolic acid), oxaliplatin-containing, and tirapazamine-containing nanoparticles, have also been coated with cancer cell membranes [173,172,176,177].

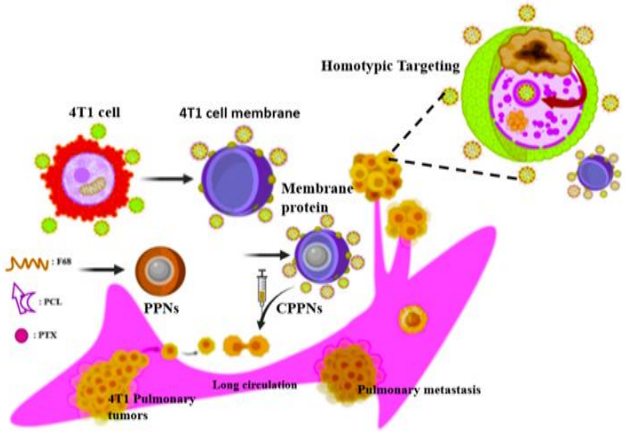


**Figure 2:** Diagrammatic illustration of biomimetic nanoparticles coated with cancer cell membranes enabling homotypic targeting of 4T1 cancer cells in both primary and metastatic tumors

### 3.3. Nature-inspired Nanomaterials

A relatively new and still unknown area of study is the biosynthesis of nanomaterials. Inorganic compounds with sizes of Nano and microns are produced by a multitude of techniques that nature has evolved. During the bottom-up process of nanoparticle production, reduction/oxidation is the main reaction. It is frequently plant phytochemicals with reducing or antioxidant properties or microbial enzymes that reduce metal compounds into their equivalent nanoparticles. They mostly include of:

#### a) Use of bacteria to synthesize nanomaterials

In both surface and subsurface settings, bacteria are essential to the biogeochemical cycling of metals and the production of minerals [178,179]. An innovative method for producing metal nanoparticles is the utilization of microbial cells to synthesize materials at the nanoscale. Although efforts to biosynthesize nanomaterials are relatively new, the interlinkage in-between microorganisms and metals have been validated, and the potential of microorganisms to elicit and/or aggregate metals which were required for marketed biotechnological techniques like bioleaching and bioremediation [180]. Bacteria are used to synthesize gold, silver, and cadmium sulfide nanoparticles because of their capacity to produce inorganic materials both extracellularly and intracellularly. Magneto tactic bacteria, which create nanoparticle with magnetic property and bacteria of S-layer type and thus they create calcium carbonate and gypsum layers, are examples of bacteria that synthesize inorganic materials [181]. Moreover, it has also been demonstrated that Pseudomonas stutzeri AG 259, which was segregated from silver mining and thus yield silver nanoparticles [182].

#### b) Use of fungi to synthesize nanoparticles

The synthesis of MNP mediated by fungi is a relatively new field of study. The production of nanoparticles has been extensively facilitated by fungi, and for certain of them, the mechanistic features influencing the generation of nanoparticles have also been reported. Fungi can be used to produce nanoparticles with precisely specified dimensions in addition to monodispersity. Fungi have the potential to be a more abundant generator of nanoparticles than bacteria. This is because more proteins are secreted by fungus, and greater protein translation translates into more productive creation of nanoparticles [182].

Yeast, a member of the fungal class Ascomycetes, has demonstrated significant promise in the generation of nanoparticles. The fungus V. luteoalbum has been used to create intracellular gold nanoparticles. Physical factors including pH, temperature, exposure duration, and metal (gold) concentration may be controlled to some extent to influence the production rate of the nanoparticles along with their size. A biological mechanism that could thus precisely regulate the particle form would be very beneficial [180]. Ascomycetes, which include yeast, have demonstrated significant promise for the creation of nanoparticles. It was shown that Schizosaccharomyces pombe cells could make semiconductor CdS nanocrystals, with their production peaking in the middle of the growth log phase. During the initial exponential phase of yeast development [183], the addition of Cd exerted an effect on the organism's metabolism. It has been suggested that Baker's yeast, Saccharomyces cerevisiae, may be a viable option for transforming $Sb_2O_3$ nanoparticles, and the organism's resistance to $Sb_2O_3$ has also been evaluated. In this setting nanoparticles in a range of 2-10 nm of size were produced.

#### c) Use of plants to synthesize nanoparticles

One advantage of using plants to generate nanoparticles is to induce investigation of nanoparticles production required for various plants ongoing due to their well-being, ease of approachability, comprehensive range of metabolites that facilitate reduction, 2-20 nm in size Gold nanoparticles, along with Niobium, Cobalt, Zinc, Copper, and Silver nanoparticles, have been synthesized using various live plant species, including Medicago sativa (alfalfa), Helianthus annus (sunflower), and Brassica juncea (Indian mustard )[184].Plant that have been proven to gather metal concentration with elevated range are called hyper accumulators and the above listed plants are under examination especially Brassica juncea which has greatest ability to aggregate metals with successive integration of nanoparticles. The main responsibility of phytochemicals in the plant-facilitated declination of metallic nanoparticle which has been marked for multiple examination in current time. The crucial phytochemicals which are suggested are terpenoids, flavones, ketones, aldehydes, amides and carboxylic acid and thus it deploy the need of infrared

spectroscopy. Flavones, organic acids, and quinones are the foremost water-soluble phytochemicals that yield an instant declination in concentration. The synthesis of silver nanoparticles was studied with respect to the phytochemicals present in Cyprus sp. (Mesophytes), Bryophyllum sp. (Xerophytes), and Hydrilla sp. (Hydrophytes).

### 3.4. Application in Cancer Therapy

Green nanotechnology offers various applications in cancer therapy-

- **Targeted Drug Delivery:** Green nanotechnology enables the development of Nano carriers or nanoparticles that can carry anticancer drugs specifically to tumor sites. These Nano carriers can be modified to selectively bind to cancer cells, enhancing drug delivery while minimizing damage to healthy tissues. Furthermore, eco-friendly synthesis methods can be employed to produce these Nano carriers, reducing the impact on the environment.
- **Photo thermal therapy:** Gold or carbon-based nanoparticles are examples of materials that can be used in photo thermal therapy. These nanoparticles have the ability to specifically kill cancer cells by absorbing light energy and converting it into heat. The creation of biocompatible nanoparticles and environmentally friendly synthesis techniques are the main goals of green nanotechnology in this therapeutic area.
- **Green nanotechnology:** It can improve cancer imaging methods like fluorescence imaging or magnetic resonance imaging, which are used to image malignant cells or tissue. Tumor detection accuracy can be increased by engineering nanoparticles to improve contrast in imaging modalities. Furthermore, ecologically sustainable methods may be employed for the synthesis of these contrast agents.
- **Biosensors:** Green nanotechnology can contribute to the development of biosensors that can detect cancer biomarkers at an early stage. Using sustainable nanomaterials, such as graphene or carbon nanotubes, these biosensors can provide rapid and sensitive detection of cancer-related molecules in body fluids, enabling early diagnosis and treatment.
- **Theranostics:** Green nanotechnology enables the integration of diagnostics and therapy into a single platform called theranostics. Sustainable nanomaterial can be engineered to simultaneously deliver therapy and provide real-time monitoring of treatment effectiveness through imaging or sensing. This approach can lead to personalized cancer treatment and reduced environmental impact.

## Conclusion and future perspectives of Green Nanotechnology

Continued research and investment in green nanotechnology for cancer therapy hold the potential for groundbreaking advancements. The field may see the synthesis of novel nanomaterials with better drug delivery systems, and elevated imaging methods for preliminary cancer determination. Utilizing green nanotechnology in cancer therapy offers a novel and exciting way to deal with the problems that come with traditional cancer therapies. Green nanotechnology is the use of nanotechnology methods and ideas combined with sustainable and eco-friendly activities. Notwithstanding the potential, issues including long-term safety, repeatability, and scalability must be resolved. It could take additional research and advancement to advance green nanotechnology from laboratories to therapeutic uses.

In conclusion, green nanotechnology in cancer therapy is an evolving field that offers a range of benefits, including improved safety, targeted drug delivery, and reduced environmental impact. Green nanotechnology appears to have a bright future in the battle against cancer, despite obstacles still being faced by researchers and multidisciplinary teams working together. Keeping up with the most recent advancements in this quickly developing sector is crucial.

**Source of Support:** The author(s) received no financial support for the research, authorship, and/or publication of this article

**Conflict of Interest:** The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## REFERENCES

1. Nair B, Pradeep T. Coalescence of nanoclusters and formation of submicron crystallites assisted by Lactobacillus strains. Crystal growth & design. 2002 Jul 3;2(4):293-8.
2. Dameron CT, Reese RN, Mehra RK, Kortan AR, Carroll PJ, Steigerwald ML, Brus LE, Winge DR. Biosynthesis of cadmium sulphide quantum semiconductor crystallites. Nature. 1989 Apr 13;338(6216):596-7.
3. Hullmann A, Meyer M. Publications and patents in nanotechnology. Scientometrics. 2003 Nov 1;58(3):507-27.Zou, H.; Wu, S.; Shen, J. Polymer/silica nanocomposites: Preparation, characterization, properties, and applications. Chem. Rev. 2008, 108, 3893–3957.
4. Zou H, Wu S, Shen J. Polymer/silica nanocomposites: preparation, characterization, properties, and applications. Chemical reviews. 2008 Sep 10;108(9):3893-957.
5. Anastas PT, Warner JC. Green chemistry: theory and practice. Oxford university press; 2000 May 25.Abraham, M.A., Nguyen, N., 2003. Green engineering: defining the principles—results from the Sandestin conference. Environ. Prog. 22 (4), 233–236.
6. Abraham MA, Nguyen N. "Green engineering: Defining the principles"—resdts from the sandestin conference. Environmental Progress. 2003 Dec;22(4):233-6.
7. Khosa A, Reddi S, Saha RN. Nanostructured lipid carriers for site-specific drug delivery. Biomedicine & Pharmacotherapy. 2018 Jul 1;103:598-613.
8. Jahangirian H, Lemraski EG, Webster TJ, Rafiee-Moghaddam R, Abdollahi Y. A review of drug delivery systems based on nanotechnology and green chemistry: green nanomedicine. International journal of nanomedicine. 2017 Apr 12:2957-78.

9. Sunderland CJ, Steiert M, Talmadge JE, Derfus AM, Barry SE. Targeted nanoparticles for detecting and treating cancer. Drug Development Research. 2006 Jan;67(1):70-93.
10. Silva R, Ferreira H, Cavaco-Paulo A. Sonoproduction of liposomes and protein particles as templates for delivery purposes. Biomacromolecules. 2011 Oct 10;12(10):3353-68.
11. Santos Giuberti CD, de Oliveira Reis EC, Ribeiro Rocha TG, Leite EA, Lacerda RG, Ramaldes GA, de Oliveira MC. Study of the pilot production process of long-circulating and pH-sensitive liposomes containing cisplatin. Journal of liposome research. 2011 Mar 1;21(1):60-9.
12. Afergan E, Epstein H, Dahan R, Koroukhov N, Rohekar K, Danenberg HD, Golomb G. Delivery of serotonin to the brain by monocytes following phagocytosis of liposomes. Journal of Controlled Release. 2008 Dec 8;132(2):84-90.
13. Turkova A, Roilides E, Sharland M. Amphotericin B in neonates: deoxycholate or lipid formulation as first-line therapy–is there a 'right'choice?. Current opinion in infectious diseases. 2011 Apr 1;24(2):163-71.
14. Yukihara M, Ito K, Tanoue O, Goto K, Matsushita T, Matsumoto Y, Masuda M, Kimura S, Ueoka R. Effective drug delivery system for duchenne muscular dystrophy using hybrid liposomes including gentamicin along with reduced toxicity. Biological and Pharmaceutical Bulletin. 2011 May 1;34(5):712-6.
15. Paavola A, Kilpeläinen I, Yliruusi J, Rosenberg P. Controlled release injectable liposomal gel of ibuprofen for epidural analgesia. International journal of pharmaceutics. 2000 Apr 10;199(1):85-93.
16. van den Hoven JM, Van Tomme SR, Metselaar JM, Nuijen B, Beijnen JH, Storm G. Liposomal drug formulations in the treatment of rheumatoid arthritis. Molecular pharmaceutics. 2011 Aug 1;8(4):1002-15.
17. Wissing SA, Kayser O, Müller RH. Solid lipid nanoparticles for parenteral drug delivery. Advanced drug delivery reviews. 2004 May 7;56(9):1257-72.
18. Abdel-Mottaleb MM, Neumann D, Lamprecht A. Lipid nanocapsules for dermal application: a comparative study of lipid-based versus polymer-based nanocarriers. European Journal of Pharmaceutics and Biopharmaceutics. 2011 Sep 1;79(1):36-42.
19. Muchow M, Maincent P, Müller RH. Lipid nanoparticles with a solid matrix (SLN®, NLC®, LDC®) for oral drug delivery. Drug development and industrial pharmacy. 2008 Jan 1;34(12):1394-405.
20. Nayak AP, Tiyaboonchai W, Patankar S, Madhusudhan B, Souto EB. Curcuminoids-loaded lipid nanoparticles: novel approach towards malaria treatment. Colloids and Surfaces B: Biointerfaces. 2010 Nov 1;81(1):263-73.
21. Attama AA, Schicke BC, Paepenmüller T, Müller-Goymann CC. Solid lipid nanodispersions containing mixed lipid core and a polar heterolipid: characterization. European Journal of Pharmaceutics and Biopharmaceutics. 2007 Aug 1;67(1):48-57.
22. Liu J, Gong T, Fu H, Wang C, Wang X, Chen Q, Zhang Q, He Q, Zhang Z. Solid lipid nanoparticles for pulmonary delivery of insulin. International journal of pharmaceutics. 2008 May 22;356(1-2):333-44.
23. Sznitowska M, Gajewska M, Janicki S, Radwanska A, Lukowski G. Bioavailability of diazepam from aqueous-organic solution, submicron emulsion and solid lipid nanoparticles after rectal administration in rabbits. European journal of pharmaceutics and biopharmaceutics. 2001 Sep 1;52(2):159-63.
24. Kovacevic A, Savic S, Vuleta G, Mueller RH, Keck CM. Polyhydroxy surfactants for the formulation of lipid nanoparticles (SLN and NLC): effects on size, physical stability and particle matrix structure. International journal of pharmaceutics. 2011 Mar 15;406(1-2):163-72.
25. Müller RH, Radtke M, Wissing S. Nanostructured lipid matrices for improved microencapsulation of drugs. International journal of pharmaceutics. 2002 Aug 21;242(1-2):121-8.
26. Wissing SA, Kayser O, Müller RH. Solid lipid nanoparticles for parenteral drug delivery. Advanced drug delivery reviews. 2004 May 7;56(9):1257-72.
27. Bilensoy E, Sarisozen C, Esendağlı G, Doğan AL, Aktaş Y, Şen M, Mungan NA. Intravesical cationic nanoparticles of chitosan and polycaprolactone for the delivery of Mitomycin C to bladder tumors. International journal of pharmaceutics. 2009 Apr 17;371(1-2):170-6.
28. Bai J, Li Y, Du J, Wang S, Zheng J, Yang Q, Chen X. One-pot synthesis of polyacrylamide-gold nanocomposite. Materials Chemistry and Physics. 2007 Dec 15;106(2-3):412-5.
29. Turos E, Shim JY, Wang Y, Greenhalgh K, Reddy GS, Dickey S, Lim DV. Antibiotic-conjugated polyacrylate nanoparticles: new opportunities for development of anti-MRSA agents. Bioorganic & medicinal chemistry letters. 2007 Jan 1;17(1):53-6.
30. Martínez A, Iglesias I, Lozano R, Teijón JM, Blanco MD. Synthesis and characterization of thiolated alginate-albumin nanoparticles stabilized by disulfide bonds. Evaluation as drug delivery systems. Carbohydrate polymers. 2011 Jan 30;83(3):1311-21..
31. Mao HQ, Roy K, Troung-Le VL, Janes KA, Lin KY, Wang Y, August JT, Leong KW. Chitosan-DNA nanoparticles as gene carriers: synthesis, characterization and transfection efficiency. Journal of controlled release. 2001 Feb 23;70(3):399-421.
32. Rejinold NS, Chennazhi KP, Nair SV, Tamura H, Jayakumar R. Biodegradable and thermo-sensitive chitosan-g-poly (N-vinylcaprolactam) nanoparticles as a 5-fluorouracil carrier. Carbohydrate polymers. 2011 Jan 10;83(2):776-86.
33. Saraogi GK, Gupta P, Gupta UD, Jain NK, Agrawal GP. Gelatin nanocarriers as potential vectors for effective management of tuberculosis. International journal of pharmaceutics. 2010 Jan 29;385(1-2):143-9.
34. Mainardes RM, Khalil NM, Gremião MP. Intranasal delivery of zidovudine by PLA and PLA–PEG blend nanoparticles. International Journal of Pharmaceutics. 2010 Aug 16;395(1-2):266-71.
35. Park J, Fong PM, Lu J, Russell KS, Booth CJ, Saltzman WM, Fahmy TM. PEGylated PLGA nanoparticles for the improved delivery of doxorubicin. InNanomedicine in Cancer 2017 Sep 1 (pp. 575-596). Jenny Stanford Publishing.
36. Fritzen-Garcia MB, Zanetti-Ramos BG, de Oliveira CS, Soldi V, Pasa AA, Creczynski-Pasa TB. Atomic force microscopy imaging of polyurethane nanoparticles onto different solid substrates. Materials Science and Engineering: C. 2009 Mar 1;29(2):405-9.
37. Mora-Huertas CE, Fessi H, Elaissari A. Polymer-based nanocapsules for drug delivery. International journal of pharmaceutics. 2010 Jan 29;385(1-2):113-42.
38. Luo G, Yu X, Jin C, Yang F, Fu D, Long J, Xu J, Zhan C, Lu W. LyP-1-conjugated nanoparticles for targeting drug delivery to lymphatic metastatic tumors. International journal of pharmaceutics. 2010 Jan 29;385(1-2):150-6.
39. Torchilin V. Multifunctional pharmaceutical nanocarriers: development of the concept. InMultifunctional pharmaceutical nanocarriers 2008 Mar 21 (pp. 1-32). New York, NY: Springer New York.
40. Svenson S, Tomalia DA. Dendrimers in biomedical applications—reflections on the field. Advanced drug delivery reviews. 2012 Dec 1;64:102-15.
41. Caminade AM, Laurent R, Majoral JP. Characterization of dendrimers. Advanced drug delivery reviews. 2005 Dec 14;57(15):2130-46.
42. Shi L, Fleming CJ, Riechers SL, Yin NN, Luo J, Lam KS, Liu GY. High-resolution imaging of dendrimers used in drug delivery via scanning probe microscopy. Journal of drug delivery. 2011;2011.

43. Yu H, Nie Y, Dohmen C, Li Y, Wagner E. Epidermal growth factor–PEG functionalized PAMAM-pentaethylenehexamine dendron for targeted gene delivery produced by click chemistry. Biomacromolecules. 2011 Jun 13;12(6):2039-47.

44. D'Emanuele A, Attwood D. Dendrimer–drug interactions. Advanced drug delivery reviews. 2005 Dec 14;57(15):2147-62.

45. Malik N, Evagorou EG, Duncan R. Dendrimer-platinate: a novel approach to cancer chemotherapy. Anti-cancer drugs. 1999 Sep 1;10(8):767-76.

46. Czarnobaj K. Preparation and characterization of silica xerogels as carriers for drugs. Drug delivery. 2008 Jan 1;15(8):485-92.

47. Slowing II, Trewyn BG, Giri S, Lin VY. Mesoporous silica nanoparticles for drug delivery and biosensing applications. Advanced Functional Materials. 2007 May 21;17(8):1225-36.

48. Echeverría JC, Estella J, Barbería V, Musgo J, Garrido JJ. Synthesis and characterization of ultramicroporous silica xerogels. Journal of Non-Crystalline Solids. 2010 Mar 1;356(6-8):378-82.

49. Czarnobaj K. Preparation and characterization of silica xerogels as carriers for drugs. Drug delivery. 2008 Jan 1;15(8):485-92.

50. Quintanar-Guerrero D, Ganem-Quintanar A, Nava-Arzaluz MG, Piñón-Segundo E. Silica xerogels as pharmaceutical drug carriers. Expert opinion on drug delivery. 2009 May 1;6(5):485-98.

51. Fidalgo A, Lopez TM, Ilharco LM. Wet sol–gel silica matrices as delivery devices for phenytoin. Journal of sol-gel science and technology. 2009 Mar;49:320-8.

52. Prokopowicz M. Synthesis and in vitro characterization of freeze-dried doxorubicin-loaded silica xerogels. Journal of sol-gel science and technology. 2010 Mar;53:525-33.

53. Czarnobaj K, Łukasiak J. In vitro release of cisplatin from sol–gel processed organically modified silica xerogels. Journal of Materials Science: Materials in Medicine. 2007 Oct;18:2041-4.

54. Czarnobaj K, Sawicki W. The sol-gel prepared SiO2-CaO-P2O5 composites doped with Metronidazole for application in local delivery systems. Pharmaceutical Development and Technology. 2012 Dec 1;17(6):697-704.

55. Wei L, Hu N, Zhang Y. Synthesis of polymer—mesoporous silica nanocomposites. Materials. 2010 Jul 13;3(7):4066-79.

56. Di Pasqua AJ, Wallner S, Kerwood DJ, Dabrowiak JC. Adsorption of the PtII anticancer drug carboplatin by mesoporous silica. Chemistry & biodiversity. 2009 Sep;6(9):1343-9.

57. He Q, Gao Y, Zhang L, Zhang Z, Gao F, Ji X, Li Y, Shi J. A pH-responsive mesoporous silica nanoparticles-based multi-drug delivery system for overcoming multi-drug resistance. Biomaterials. 2011 Oct 1;32(30):7711-20.

58. Li Z, Su K, Cheng B, Deng Y. Organically modified MCM-type material preparation and its usage in controlled amoxicillin delivery. Journal of colloid and interface science. 2010 Feb 15;342(2):607-13.

59. Popovici RF, Seftel EM, Mihai GD, Popovici E, Voicu VA. Controlled drug delivery system based on ordered mesoporous silica matrices of captopril as angiotensin-converting enzyme inhibitor drug. Journal of pharmaceutical sciences. 2011 Feb 1;100(2):704-14.

60. Beg S, Rizwan M, Sheikh AM, Hasnain MS, Anwer K, Kohli K. Advancement in carbon nanotubes: basics, biomedical applications and toxicity. Journal of pharmacy and pharmacology. 2011 Feb;63(2):141-63.

61. Foldvari M, Bagonluri M. Carbon Nanotubes as Functional Excipients for Nanomedicines: II. Pharmaceutical Properties. Nanomedicine in Cancer. 2017 Sep 1:523-48.

62. Zhang B, Chen Q, Tang H, Xie Q, Ma M, Tan L, Zhang Y, Yao S. Characterization of and biomolecule immobilization on the biocompatible multi-walled carbon nanotubes generated by functionalization with polyamidoamine dendrimers. Colloids and Surfaces B: biointerfaces. 2010 Oct 1;80(1):18-25.

63. Di Crescenzo A, Velluto D, Hubbell JA, Fontana A. Biocompatible dispersions of carbon nanotubes: a potential tool for intracellular transport of anticancer drugs. Nanoscale. 2011;3(3):925-8.

64. Bhirde AA, Patel S, Sousa AA, Patel V, Molinolo AA, Ji Y, Leapman RD, Gutkind JS, Rusling JF. Distribution and clearance of PEG-single-walled carbon nanotube cancer drug delivery vehicles in mice. Nanomedicine. 2010 Dec;5(10):1535-46.

65. Shin US, Yoon IK, Lee GS, Jang WC, Knowles JC, Kim HW. Carbon nanotubes in nanocomposites and hybrids with hydroxyapatite for bone replacements. Journal of tissue engineering. 2011;2011.

66. Arsawang U, Saengsawang O, Rungrotmongkol T, Sornmee P, Wittayanarakul K, Remsungnen T, Hannongbua S. How do carbon nanotubes serve as carriers for gemcitabine transport in a drug delivery system?. Journal of Molecular Graphics and Modelling. 2011 Feb 1;29(5):591-6.

67. Tripisciano C, Costa S, Kalenczuk RJ, Borowiak-Palen E. Cisplatin filled multiwalled carbon nanotubes–a novel molecular hybrid of anticancer drug container. The European Physical Journal B. 2010 May;75:141-6.

68. Chen Z, Pierre D, He H, Tan S, Pham-Huy C, Hong H, Huang J. Adsorption behavior of epirubicin hydrochloride on carboxylated carbon nanotubes. International journal of pharmaceutics. 2011 Feb 28;405(1-2):153-61.

69. Zhang D, Pan B, Wu M, Wang B, Zhang H, Peng H, Wu D, Ning P. Adsorption of sulfamethoxazole on functionalized carbon nanotubes as affected by cations and anions. Environmental pollution. 2011 Oct 1;159(10):2616-21.

70. Perry JL, Martin CR, Stewart JD. Drug-Delivery Strategies by Using Template-Synthesized Nanotubes. Chemistry–A European Journal. 2011 May 27;17(23):6296-302.

71. Luo X, Matranga C, Tan S, Alba N, Cui XT. Carbon nanotube nanoreservior for controlled release of anti-inflammatory dexamethasone. Biomaterials. 2011 Sep 1;32(26):6316-23.

72. Dhar S, Liu Z, Thomale J, Dai H, Lippard SJ. Targeted single-wall carbon nanotube-mediated Pt (IV) prodrug delivery using folate as a homing device. Journal of the American Chemical Society. 2008 Aug 27;130(34):11467-76.

73. Bhirde AA, Patel V, Gavard J, Zhang G, Sousa AA, Masedunskas A, Leapman RD, Weigert R, Gutkind JS, Rusling JF. Targeted killing of cancer cells in vivo and in vitro with EGF-directed carbon nanotube-based drug delivery. ACS nano. 2009 Feb 24;3(2):307-16.

74. Shiba K, Yudasaka M, Iijima S. Carbon nanohorns as a novel drug carrier. Nihon rinsho. Japanese journal of clinical medicine. 2006 Feb 1;64(2):239-46.

75. Arruebo M, Fernández-Pacheco R, Ibarra MR, Santamaría J. Magnetic nanoparticles for drug delivery. Nano today. 2007 Jun 1;2(3):22-32.

76. Meng X, Seton HC, Lu LT, Prior IA, Thanh NT, Song B. Magnetic CoPt nanoparticles as MRI contrast agent for transplanted neural stem cells detection. Nanoscale. 2011;3(3):977-84.

77. Kale SN, Jadhav AD, Verma S, Koppikar SJ, Kaul-Ghanekar R, Dhole SD, Ogale SB. Characterization of biocompatible NiCo2O4 nanoparticles for applications in hyperthermia and drug delivery. Nanomedicine: Nanotechnology, Biology and Medicine. 2012 May 1;8(4):452-9.

78. Sayed FN, Jayakumar OD, Sudakar C, Naik R, Tyagi AK. Possible weak ferromagnetism in pure and M (Mn, Cu, Co, Fe and Tb) doped NiGa2O4 nanoparticles. Journal of nanoscience and nanotechnology. 2011 Apr 1;11(4):3363-9.

79. Smolensky ED, Park HY, Berquó TS, Pierre VC. Surface functionalization of magnetic iron oxide nanoparticles for MRI applications–effect of anchoring group and ligand exchange protocol. Contrast media & molecular imaging. 2011 Jul;6(4):189-99.

80. Figuerola A, Di Corato R, Manna L, Pellegrino T. From iron oxide nanoparticles towards advanced iron-based inorganic materials designed for biomedical applications. Pharmacological Research. 2010 Aug 1;62(2):126-43.

81. Asmatulu R, Zalich MA, Claus RO, Riffle JS. Synthesis, characterization and targeting of biodegradable magnetic nanocomposite particles by external magnetic fields. Journal of Magnetism and Magnetic Materials. 2005 Apr 1;292:108-19.

82. Tamer U, Gündoğdu Y, Boyacı İH, Pekmez K. Synthesis of magnetic core–shell Fe 3 O 4–Au nanoparticle for biomolecule immobilization and detection. Journal of Nanoparticle Research. 2010 May;12:1187-96.

83. Chomoucka J, Drbohlavova J, Huska D, Adam V, Kizek R, Hubalek J. Magnetic nanoparticles and targeted drug delivering. Pharmacological research. 2010 Aug 1;62(2):144-9.

84. Chang JH, Kang KH, Choi J, Jeong YK. High efficiency protein separation with organosilane assembled silica coated magnetic nanoparticles. Superlattices and Microstructures. 2008 Oct 1;44(4-5):442-8.

85. Grassi-Schultheiss PP, Heller F, Dobson J. Analysis of magnetic material in the human heart, spleen and liver. Biometals. 1997 Dec;10:351-5.

86. Figuerola A, Di Corato R, Manna L, Pellegrino T. From iron oxide nanoparticles towards advanced iron-based inorganic materials designed for biomedical applications. Pharmacological Research. 2010 Aug 1;62(2):126-43.

87. Yallapu MM, Othman SF, Curtis ET, Gupta BK, Jaggi M, Chauhan SC. Multi-functional magnetic nanoparticles for magnetic resonance imaging and cancer therapy. Biomaterials. 2011 Mar 1;32(7):1890-905.

88. Wu W, Chen B, Cheng J, Wang J, Xu W, Liu L, Xia G, Wei H, Wang X, Yang M, Yang L. Biocompatibility of Fe3O4/DNR magnetic nanoparticles in the treatment of hematologic malignancies. International journal of nanomedicine. 2010 Dec 2:1079-84.

89. Mittal AK, Chisti Y, Banerjee UC. Synthesis of metallic nanoparticles using plant extracts. Biotechnology advances. 2013 Mar 1;31(2):346-56.

90. Yi S, Wang Y, Huang Y, Xia L, Sun L, Lenaghan SC, Zhang M. Tea nanoparticles for immunostimulation and chemo-drug delivery in cancer treatment. Journal of biomedical nanotechnology. 2014 Jun 1;10(6):1016-29.

91. Mohammadinejad R, Karimi S, Iravani S, Varma RS. Plant-derived nanostructures: types and applications. Green Chemistry. 2016;18(1):20-52.

92. Pum D, Sleytr UB. The application of bacterial S-layers in molecular nanotechnology. Trends in Biotechnology. 1999 Jan 1;17(1):8-12.

93. Milligan AJ, Morel FM. A proton buffering role for silica in diatoms. Science. 2002 Sep 13;297(5588):1848-50.

94. Lovley DR, Stolz JF, Nord Jr GL, Phillips EJ. Anaerobic production of magnetite by a dissimilatory iron-reducing microorganism. Nature. 1987 Nov 19;330(6145):252-4.

95. Kesharwani J, Yoon KY, Hwang J, Rai M. Phytofabrication of silver nanoparticles by leaf extract of Datura metel: hypothetical mechanism involved in synthesis. Journal of Bionanoscience. 2009 Jun 1;3(1):39-44.

96. Klaus-Joerger T, Joerger R, Olsson E, Granqvist CG. Bacteria as workers in the living factory: metal-accumulating bacteria and their potential for materials science. TRENDS in Biotechnology. 2001 Jan 1;19(1):15-20.

97. Bruins MR, Kapil S, Oehme FW. Microbial resistance to metals in the environment. Ecotoxicology and environmental safety. 2000 Mar 1;45(3):198-207.

98. Beveridge TJ, Hughes MN, Lee H, Leung KT, Poole RK, Savvaidis I, Silver S, Trevors JT. Metal-microbe interactions: contemporary approaches. Advances in microbial physiology. 1996 Jan 1;38:177-243.

99. Bao C, Jin M, Lu R, Zhang T, Zhao YY. Preparation of Au nanoparticles in the presence of low generational poly (amidoamine) dendrimer with surface hydroxyl groups. Materials chemistry and physics. 2003 Jul 20;81(1):160-5.

100. Sharma NC, Sahi SV, Nath S, Parsons JG, Gardea-Torresdey JL, Pal T. Environ Sci Technol 2007;41:5137.

101. Mann S. Bacteria and the Midas touch. Nature. 1992 Jun 4;357(6377):358-60.

102. Beveridge TJ, Murray RG. Sites of metal deposition in the cell wall of Bacillus subtilis. Journal of bacteriology. 1980 Feb;141(2):876-87.

103. Southam G, Beveridge TJ. The in vitro formation of placer gold by bacteria. Geochimica et Cosmochimica Acta. 1994 Oct 1;58(20):4527-30.

104. Lengke M, Southam G. Bioaccumulation of gold by sulfate-reducing bacteria cultured in the presence of gold (I)-thiosulfate complex. Geochimica et cosmochimica Acta. 2006 Jul 15;70(14):3646-61.

105. Kashefi K, Tor JM, Nevin KP, Lovley DR. Appl Environ Microbiol 2001;67:3275.

106. Konishi Y, Tsukiyama T, Tachimi T, Saitoh N, Nomura T, Nagamine S. Microbial deposition of gold nanoparticles by the metal-reducing bacterium Shewanella algae. Electrochimica Acta. 2007 Nov 20;53(1):186-92.

107. Feng Y, Yu Y, Wang Y, Lin X. Biosorption and bioreduction of trivalent aurum by photosynthetic bacteria Rhodobacter capsulatus. Current Microbiology. 2007 Nov;55:402-8.

108. He S, Guo Z, Zhang Y, Zhang S, Wang J, Gu N. Biosynthesis of gold nanoparticles using the bacteria Rhodopseudomonas capsulata. Materials Letters. 2007 Jul 1;61(18):3984-7.

109. He S, Zhang Y, Guo Z, Gu N. Biological synthesis of gold nanowires using extract of Rhodopseudomonas capsulata. Biotechnology Progress. 2008 Mar;24(2):476-80.

110. Schmid G. Large clusters and colloids. Metals in the embryonic state. Chemical reviews. 1992 Dec 1;92(8):1709-27.

111. Henglein A. Small-particle research: physicochemical properties of extremely small colloidal metal and semiconductor particles. Chemical reviews. 1989 Dec 1;89(8):1861-73.

112. Alivisatos AP, Johnsson KP, Peng X, Wilson TE, Loweth CJ, Bruchez Jr MP, Schultz PG. Organization of'nanocrystal molecules' using DNA. Nature. 1996 Aug 15;382(6592):609-11.

113. Mirkin CA, Letsinger RL, Mucic RC, Storhoff JJ. A DNA-based method for rationally assembling nanoparticles into macroscopic materials. InSpherical Nucleic Acids 2020 Aug 31 (pp. 3-11). Jenny Stanford Publishing.

114. Braun E, Eichen Y, Sivan U, Ben-Yoseph G. DNA-templated assembly and electrode attachment of a conducting silver wire. Nature. 1998 Feb 19;391(6669):775-8.

115. Wong KK, Douglas T, Gider S, Awschalom DD, Mann S. Biomimetic synthesis and characterization of magnetic proteins (magnetoferritin). Chemistry of materials. 1998 Jan 19;10(1):279-85.

116. Archibald DD, Mann S. Template mineralization of self-assembled anisotropic lipid microstructures. Nature. 1993 Jul 29;364(6436):430-3.

117. Baral S, Schoen P. Silica-deposited phospholipid tubules as a precursor to hollow submicron-diameter silica cylinders. Chemistry of materials. 1993 Feb 1;5(2):145-7.

118. Douglas T, Young M. Host–guest encapsulation of materials by assembled virus protein cages. Nature. 1998 May 14;393(6681):152-5.

119. Pazirandeh M, Baral S, Campbell J. Metallized nanotubules derived from bacteria. Biomimetics. 1992;1(1):41-50.

120. Shenton W, Pum D, Sleytr UB, Mann S. Synthesis of cadmium sulphide superlattices using self-assembled bacterial S-layers. Nature. 1997 Oct 9;389(6651):585-7.

121. Davis SA, Burkett SL, Mendelson NH, Mann S. Bacterial templating of ordered macrostructures in silica and silica-surfactant mesophases. Nature. 1997 Jan 30;385(6615):420-3.

122. Shenton W, Douglas T, Young M, Stubbs G, Mann S. Inorganic–organic nanotube composites from template mineralization of tobacco mosaic virus. Advanced Materials. 1999 Mar;11(3):253-6.

123. Anastas PT, Warner JC. Green chemistry: theory and practice. Oxford university press; 2000 May 25.

124. Anastas PT, Williamson TC, editors. Green chemistry: designing chemistry for the environment. American Chemical Society; 1996 May 5.

125. Centi G, Perathoner S. From green to sustainable industrial chemistry. Sustainable industrial chemistry. 2009 Sep 22:1-72.

126. Tiwari DK, Behari J, Sen P. Time and dose-dependent antimicrobial potential of Ag nanoparticles synthesized by top-down approach. Current Science. 2008 Sep 10:647-55.

127. Gupta V, Gupta AR, Kant V. Synthesis, characterization and biomedical application of nanoparticles. Science International. 2013;1(5):167-74.

128. Pal SL, Jana U, Manna PK, Mohanta GP, Manavalan R. Nanoparticle: An overview of preparation and characterization. Journal of applied pharmaceutical science. 2011 Aug 30(Issue):228-34.

129. Kowalczyk B, Lagzi I, Grzybowski BA. Nanoseparations: Strategies for size and/or shape-selective purification of nanoparticles. Current Opinion in Colloid & Interface Science. 2011 Apr 1;16(2):135-48.

130. Brice-Profeta S, Arrio MA, Tronc E, Menguy N, Letard I, dit Moulin CC, Nogues M, Chanéac C, Jolivet JP, Sainctavit P. Magnetic order in γ-Fe2O3 nanoparticles: a XMCD study. Journal of Magnetism and Magnetic Materials. 2005 Mar 1;288:354-65.

131. Faraji M, Yamini Y, Rezaee M. Magnetic nanoparticles: synthesis, stabilization, functionalization, characterization, and applications. Journal of the Iranian Chemical Society. 2010 Mar;7:1-37.

132. Prashanth S, Menaka I, Muthezhilan R, Sharma NK. Synthesis of plant-mediated silver nano particles using medicinal plant extract and evaluation of its anti microbial activities. International Journal of Engineering Science and Technology. 2011;3(8):6235-50.

133. Priya MM, Selvi BK, Paul JA. Green synthesis of silver nanoparticles from the leaf extracts of Euphorbia hirta and Nerium indicum. Digest Journal of Nanomaterials & Biostructures (DJNB). 2011 Apr 1;6(2).

134. Molpeceres J, Aberturas MR, Guzman M. Biodegradable nanoparticles as a delivery system for cyclosporine: preparation and characterization. Journal of microencapsulation. 2000 Jan 1;17(5):599-614.

135. Chauhan RP, Gupta C, Prakash D. Methodological advancements in green nanotechnology and their applications in biological synthesis of herbal nanoparticles. International Journal of Bioassays (IJB). 2012 Jul 6.

136. De Jaeger N, Demeyere H, Finsy R, Sneyers R, Vanderdeelen J, Van der Meeren P, Van Laethem M. Particle Sizing by Photon Correlation Spectroscopy Part I: Monodisperse latices: Influence of scattering angle and concentration of dispersed material. Particle & particle systems characterization. 1991;8(1-4):179-86.

137. Otsuka H, Nagasaki Y, Kataoka K. PEGylated nanoparticles for biological and pharmaceutical applications. Advanced drug delivery reviews. 2003 Feb 24;55(3):403-19.

138. Prasad KS, Pathak D, Patel A, Dalwadi P, Prasad R, Patel P, Selvaraj K. Biogenic synthesis of silver nanoparticles using Nicotiana tobaccum leaf extract and study of their antibacterial effect. African Journal of Biotechnology. 2011 Aug 3;10(41):8122.

139. Faraji M, Yamini Y, Rezaee M. Magnetic nanoparticles: synthesis, stabilization, functionalization, characterization, and applications. Journal of the Iranian Chemical Society. 2010 Mar;7:1-37.

140. Gupta V, Gupta AR, Kant V. Synthesis, characterization and biomedical application of nanoparticles. Science International. 2013;1(5):167-74.

141. Tiede K, Boxall AB, Tear SP, Lewis J, David H, Hassellöv M. Detection and characterization of engineered nanoparticles in food and the environment. Food additives and contaminants. 2008 Jul 1;25(7):795-821.

142. López-Serrano A, Olivas RM, Landaluze JS, Cámara C. Nanoparticles: a global vision. Characterization, separation, and quantification methods. Potential environmental and health impact. Analytical Methods. 2014;6(1):38-56.

143. Prasad KS, Pathak D, Patel A, Dalwadi P, Prasad R, Patel P, Selvaraj K. Biogenic synthesis of silver nanoparticles using Nicotiana tobaccum leaf extract and study of their antibacterial effect. African Journal of Biotechnology. 2011 Aug 3;10(41):8122.

144. Patra JK, Baek KH. Green nanobiotechnology: factors affecting synthesis and characterization techniques. Journal of Nanomaterials. 2015 Jan 1;2014:219-.

145. Vickrey TM, Garcia-Ramirez JA. Magnetic field-flow fractionation: theoretical basis. Separation Science and Technology. 1980 Jul 1;15(6):1297-304.

146. Bootz A, Vogel V, Schubert D, Kreuter J. Comparison of scanning electron microscopy, dynamic light scattering and analytical ultracentrifugation for the sizing of poly (butyl cyanoacrylate) nanoparticles. European journal of pharmaceutics and biopharmaceutics. 2004 Mar 1;57(2):369-75.

147. Mavrocordatos D, Perret D, Leppard GG. Strategies and advances in the characterisation of environmental colloids by electron microscopy. Iupac Series on Analytical and Physical Chemistry of Environmental Systems. 2007 Jan 30;10:345.

148. Balnois E, Papastavrou G, Wilkinson KJ. Force microscopy and force measurements of environmental colloids. IUPAC Series on Analytical and Physical Chemistry of Environmental Systems. 2007 Jan 30;10:405.

149. Badireddy AR, Wiesner MR, Liu J. Detection, characterization, and abundance of engineered nanoparticles in complex waters by hyperspectral imagery with enhanced darkfield microscopy. Environmental science & technology. 2012 Sep 18;46(18):10081-8.

150. Bundschuh T, Knopp R, Kim JI. Laser-induced breakdown detection (LIBD) of aquatic colloids with different laser systems. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2001 Feb 15;177(1):47-55.

151. Bundschuh T, Yun JI, Knopp R. Determination of size, concentration and elemental composition of colloids with laser-induced breakdown detection/spectroscopy (LIBD/S). Fresenius' journal of analytical chemistry. 2001 Dec;371:1063-9.

152. Peng WP, Cai Y, Lee YT, Chang HC. Laser-induced fluorescence/ion trap as a detector for mass spectrometric analysis of nanoparticles. International Journal of Mass Spectrometry. 2003 Sep 1;229(1-2):67-76.

153. Cai Y, Peng WP, Chang HC. Ion trap mass spectrometry of fluorescently labeled nanoparticles. Analytical chemistry. 2003 Apr 15;75(8):1805-11.

154. Bhargav E, Madhuri N, Ramesh K, Manne A, Ravi V. Targeted drug delivery-a review. World J Pharm Pharm Sci. 2013;3(1):150-69.

155. Vincent JF, Bogatyreva OA, Bogatyrev NR, Bowyer A, Pahl AK. Biomimetics: its practice and theory. Journal of the Royal Society Interface. 2006 Aug 22;3(9):471-82.

156. Schmitt OH. Some interesting and useful biomimetic transforms. InThird Int. Biophysics Congress 1969 Aug 29 (Vol. 1069, p. 197).

157. Pulsifer DP, Lakhtakia A, Martín-Palma RJ, Pantano CG. Mass fabrication technique for polymeric replicas of arrays of insect corneas. Bioinspiration & Biomimetics. 2010 Jul 22;5(3):036001.

158. Martín-Palma RJ, Lakhtakia A. Engineered biomimicry for harvesting solar energy: A bird's eye view. International Journal of Smart and Nano Materials. 2013 Jun 1;4(2):83-90.

159. Karthick S, Sen AK. Improved understanding of acoustophoresis and development of an acoustofluidic device for blood plasma separation. Physical Review Applied. 2018 Sep 19;10(3):034037.

160. Fang RH, Jiang Y, Fang JC, Zhang L. Cell membrane-derived nanomaterials for biomedical applications. Biomaterials. 2017 Jun 1;128:69-83.

161. Luk BT, Fang RH, Hu CM, Copp JA, Thamphiwatana S, Dehaini D, Gao W, Zhang K, Li S, Zhang L. Safe and immunocompatible nanocarriers cloaked in RBC membranes for drug delivery to treat solid tumors. Theranostics. 2016;6(7):1004.

162. Liu X, Sun Y, Xu S, Gao X, Kong F, Xu K, Tang B. Homotypic cell membrane-cloaked biomimetic nanocarrier for the targeted chemotherapy of hepatocellular carcinoma. Theranostics. 2019;9(20):5828.

163. Lai PY, Huang RY, Lin SY, Lin YH, Chang CW. Biomimetic stem cell membrane-camouflaged iron oxide nanoparticles for theranostic applications. Rsc Advances. 2015;5(119):98222-30.

164. Liu C, Zhang W, Li Y, Chang J, Tian F, Zhao F, Ma Y, Sun J. Microfluidic sonication to assemble exosome membrane-coated nanoparticles for immune evasion-mediated targeting. Nano letters. 2019 Oct 10;19(11):7836-44.

165. Li C, Yang XQ, An J, Cheng K, Hou XL, Zhang XS, Hu YG, Liu B, Zhao YD. Red blood cell membrane-enveloped O2 self-supplementing biomimetic nanoparticles for tumor imaging-guided enhanced sonodynamic therapy. Theranostics. 2020;10(2):867.

166. Van Deun J, Roux Q, Deville S, Van Acker T, Rappu P, Miinalainen I, Heino J, Vanhaecke F, De Geest BG, De Wever O, Hendrix A. Feasibility of mechanical extrusion to coat nanoparticles with extracellular vesicle membranes. Cells. 2020 Jul 29;9(8):1797.

167. Díaz-Saldívar P, Huidobro-Toro JP. ATP-loaded biomimetic nanoparticles as controlled release system for extracellular drugs in cancer applications. International Journal of Nanomedicine. 2019 Apr 5:2433-47.

168. Cao H, Dan Z, He X, Zhang Z, Yu H, Yin Q, Li Y. Liposomes coated with isolated macrophage membrane can target lung metastasis of breast cancer. ACS nano. 2016 Aug 23;10(8):7738-48.

169. Wang H, Wu J, Williams GR, Fan Q, Niu S, Wu J, Xie X, Zhu LM. Platelet-membrane-biomimetic nanoparticles for targeted antitumor drug delivery. Journal of nanobiotechnology. 2019 Dec;17:1-6.

170. Rao L, Cai B, Bu LL, Liao QQ, Guo SS, Zhao XZ, Dong WF, Liu W. Microfluidic electroporation-facilitated synthesis of erythrocyte membrane-coated magnetic nanoparticles for enhanced imaging-guided cancer therapy. Acs Nano. 2017 Apr 25;11(4):3496-505.

171. Harris JC, Scully MA, Day ES. Cancer cell membrane-coated nanoparticles for cancer management. Cancers. 2019 Nov 21;11(12):1836.

172. He Z, Zhang Y, Feng N. Cell membrane-coated nanosized active targeted drug delivery systems homing to tumor cells: A review. Materials Science and Engineering: C. 2020 Jan 1;106:110298.

173. Chen Z, Zhao P, Luo Z, Zheng M, Tian H, Gong P, Gao G, Pan H, Liu L, Ma A, Cui H. Cancer cell membrane–biomimetic nanoparticles for homologous-targeting dual-modal imaging and photothermal therapy. ACS nano. 2016 Nov 22;10(11):10049-57.

174. Lovitt CJ, Shelper TB, Avery VM. Doxorubicin resistance in breast cancer cells is mediated by extracellular matrix proteins. BMC cancer. 2018 Dec;18(1):1-1.

175. Zhang N, Li M, Sun X, Jia H, Liu W. NIR-responsive cancer cytomembrane-cloaked carrier-free nanosystems for highly efficient and self-targeted tumor drug delivery. Biomaterials. 2018 Mar 1;159:25-36.

176. Jabalera Y, Garcia-Pinel B, Ortiz R, Iglesias G, Cabeza L, Prados J, Jimenez-Lopez C, Melguizo C. Oxaliplatin–biomimetic magnetic nanoparticle assemblies for colon cancer-targeted chemotherapy: An in vitro study. Pharmaceutics. 2019 Aug 6;11(8):395.

177. Jin J, Krishnamachary B, Barnett JD, Chatterjee S, Chang D, Mironchik Y, Wildes F, Jaffee EM, Nimmagadda S, Bhujwalla ZM. Human cancer cell membrane-coated biomimetic nanoparticles reduce fibroblast-mediated invasion and metastasis and induce T-cells. ACS applied materials & interfaces. 2019 Feb 1;11(8):7850-61.

178. Lowenstam HA. Minerals formed by organisms. Science. 1981 Mar 13;211(4487):1126-31.

179. Southam G, Saunders JA. The geomicrobiology of ore deposits. Economic Geology. 2005 Sep 1;100(6):1067-84.

180. Gericke M, Pinches A. Biological synthesis of metal nanoparticles. Hydrometallurgy. 2006 Sep 1;83(1-4):132-40.

181. Shankar SS, Rai A, Ahmad A, Sastry M. Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using Neem (Azadirachta indica) leaf broth. Journal of colloid and interface science. 2004 Jul 15;275(2):496-502.

182. Mohanpuria P, Rana NK, Yadav SK. Biosynthesis of nanoparticles: technological concepts and future applications. Journal of nanoparticle research. 2008 Mar;10:507-17.

183. Kaushik P, Dhiman AK. Medicinal plants and raw drugs of India. Bishen Singh Mahendra Pal Singh; 1999.

184. Gardea-Torresdey JL, Parsons JG, Gomez E, Peralta-Videa J, Troiani HE, Santiago P, Yacaman MJ. Formation and growth of Au nanoparticles inside live alfalfa plants. Nano letters. 2002 Apr 10;2(4):397-401.