Nanotechnology: A promising tool for targeted drug delivery

Komal Mittal¹, Jyoti Sarwan¹, Bhavika Arora¹, Pragati Karn¹*, Shalu Kumari¹, Prathimesh¹, Jagadeesh Chandra Bose K¹, Deepanshu Katna², and Muskan Thakur²
¹University Institute of Biotechnology, Chandigarh University Mohali
²Post Graduate Government College-11 Chandigarh

Abstract Nanotechnology has eventually and strongly engaged in the field of drug delivery. It makes use of the specific properties of the substance at the Nano scale. Their primary goal is to increase therapeutic effects while reducing adverse effects. Due to their improved goods, nanotechnology has become more popular across a variety of industries. The term “Nano medicine” is used to denote the application of nanotechnology in medicine. This Nano medicine is essential for drug delivery, antibacterial, vaccine development, wearable technology, diagnostic and imaging tools, implants, high throughput screening platforms, etc. It makes use of biological, biomimetic, no biological, or hybrid materials. To attain logical drug delivery, it is important to understand the interlink age between nanoparticles and the biological environment, drug release, and targeting cell-surface receptors. We can control disease progression by using nanomaterial including peptide-based nanotubes to prey the vascular endothelial growth factor (VEGF) receptor. Also, the use of herbal medicine has been used since ancient times. The supply of active compounds is shown by the effectiveness of various species of herbal medicine. The essential requirements for extending novel nanotechnology-based medication delivery systems are highlighted in this review.

1 Introduction

Nanomaterials are used in the field of electronics and medicines because they have some unique properties of electrical, the surface area to volume ratio they provide is high. At the moment, nanotechnology is thought to be the upcoming technology. [1] The following characteristics can be used by scientists to comprehend and work with materials at the scale of molecules and atoms thanks to this technology:

• At least one of the nanostructure’s dimensions is 100 nm in size.
• They are produced via techniques that show early control over the chemical and physical characteristics of molecular-scale structures.

The title of the lecturer in 1959 by Richard is ‘There is plenty of room at the bottom, which gave us the idea for future elements and the significance of nanotechnology. Nanotechnology has been created to advance a number of disciplines, including engineering, chemistry, physics, robotics, biology, and medicine. [2]

In many biological areas, including medicine and the creation of therapies for a wide range of illnesses and disorders, nanotechnology is applied. Industries have some

*Corresponding author: pragatikbghs@gmail.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).
crucial effects through the medium of nanotechnology such as:

- Smarter products for medicine
- Safe and cleaner
- Long-lasting
- Better built

Cosmetics, electronics, tyres, sunscreen, athletic goods, and a number of other commonplace things are all affected by nanomaterials. Since the 1970s, controlled drug delivery systems have sought to give medications at a set and predetermined time. Delivery of drugs, on the other hand, is a well-known subject that focuses on directing genes or medications to a desired location. The fundamental goal of this targeted delivery is to deliver the right amount of medication to the targeted place, such as a tumor, cancer, or diseased tissue, while minimizing the drug's adverse effects on healthy tissue.

The demand for developing medication delivery systems is increasing due to their ability to promptly detect and respond to pathophysiological conditions. Numerous pharmaceuticals, including proteins, are being developed to target specific cellular processes. Micro- and nano-scale intelligent systems can be utilized to improve the effectiveness of therapeutic treatments by detecting and responding to diseases at specific sites, thereby enhancing the quality of life for patients. The term "intelligent therapeutics" refers to the development of sensitive and intelligent drug delivery systems that perform various functions such as isolating, detecting, and releasing therapeutic agents for treating illnesses. Researchers must integrate synthetic and hybrid materials with essential biological systems on a small scale, known as the micro- and nanoscale. Stimuli-responsive biomaterials show particular promise as carriers for creating advanced intelligent therapies. [3]

![Fig.1. How nanoparticles formed](image)

**2 Types of Nanoparticles**
Liposomes

In 1969, liposome was discovered by Alec Bangham. Liposomes are extensively studied systems used in the pharmaceutical and cosmetics industries to transport various substances for drug delivery. Composed of phospholipids and steroids, liposomes are spherical vesicles ranging from 50-450nm in size. There are four types of liposomes: (1) Conventional liposomes, which have an ionic, cationic, or neutral lipid bilayer surrounding an aqueous core; (2) PEGylated liposomes, where Polyethylene glycol (PEG) is attached to the liposome surface for steric equilibrium; (3) Ligand-targeted liposomes, where antibodies, polysaccharides, or peptides are joined to the liposome surface or the end of previously-attached PEG chains; and (4) Theranostic liposomes, which combine the characteristics of the preceding three types.[4]

The traditional liposome production process involves thin layer hydration, mechanical agitation, solvent evaporation, solvent injection, and surfactant solubilization. Drugs are encapsulated within liposomes and remain inaccessible until they are released. It is important to collect liposomes in specific areas to maximize their bioavailability within therapeutic windows at the appropriate rates and times. Liposomes utilize both active (drug encapsulated after creation) and passive (drug encapsulated during liposome synthesis) methods of drug delivery. Hydrophilic drugs like ampicillin do not require modification for encapsulation since they are commonly present in the aqueous core of the liposome. Conversely, hydrophobic drugs like Amphotericin B can be absorbed into liposomes due to the properties of the acyl chain.[5]
Fig.3. Liposome Drug Delivery

2.2 Dendrimers

They are strongly bifurcated, three-dimensional, clearly defined, and monodisperse formations. Their shape is globular and in a controlled way their surface is easily functionalized, which makes these structures as a good candidates for drug delivery. They can be linked by two different mechanisms: the divergent route, in which the dendrites start development from their core and stretch outward, and the convergent route, in which the dendrites start evolution from the outside. [6]

Dendrites are classified into various types based on their functionalization, such as PAMAM, PPI, liquid-crystalline, chiral, core-shell, glycodendrimers, peptide, and PAMAMOS. PAMAM dendrimers, being water-soluble and capable of enhancing their transfer through the paracellular pathway, have been extensively studied for oral drug delivery. However, the therapeutic application of dendrimers is limited due to the presence of amine groups, which are cationic and toxic. To overcome this toxicity issue, modifications have been made to dendrimers. Different methods of drug delivery, including covalent conjugation, simple encapsulation, and electrostatic contact, have been employed. Dendrimers have evolved for use in transdermal, oral, ocular, pulmonary, and targeted drug delivery.[4]

Doxorubicin-folate conjugated poly-L-lysine dendrimers dramatically enhanced the concentration of doxorubicin in tumours by 121.5 times after 24 hours, according to a research by Jain et al. (2014) compared to free doxorubicin. These poly-L-lysine dendrimers serve as effective carriers for cancer prevention, featuring pH-dependent drug release, antiangiogenic, anticancer properties, and target specificity. Furthermore, the utilization of folate conjugated polypropyl imine dendrimers (FA-PPI) as a nanocarrier for methotrexate (MTX) is being explored. These dendrimers offer pH-sensitive drug release, precise targeting of cancer cells, and potential anti-cancer treatment. In vitro investigations conducted using MCF-7 cell lines demonstrated sustained drug release, enhanced cell uptake, and reduced cytotoxicity.[6]

3 Antimicrobial drug delivery by solid lipid nanoparticles

Solid lipid nanoparticles are quite helpful for the drug delivery system. Since 1990 lipid nanoparticles have been serving as important nanoparticles and provide a particular drug
delivery system. The lipid nanoparticles are lie in the range of 50nm to 1000nm. Though solid lipid nanoparticles work extremely well in antimicrobial activities, there are other application of solid lipid nanoparticles exist as bio surfactant. A surfactant is defined as the substance that can reduce the surface tension of any liquid substance. The biosurfactant are surfactants that are isolated or developed from living bodies or wastes like microbial enzymes such as lipases. The following solid lipids are used for the production of solid lipid nanoparticles are palmitic acid, behenic acid, tripalmitin, trilaurin, steroids cholestrols, glyceryl mononostreate, lecithinin etc. The possible ways to formulate solid lipid nanoparticles are high shear mixing, homogenization and ultrasonication [7][8][9]

![Fig.4. Types of branching in nanoparticles](image)

**4 Quantum dots**

They are known as semiconductor nanocrystals due to their optical properties, including absorbance and photoluminescence, which are dependent on their size. Their diameters range from 2 to 10 nm.

Quantum dots (QDs) exhibit emission in the near-infrared range, making them highly desirable in the field of biomedical imaging, as they have minimal tissue absorption and reduced light dispersion compared to traditional dyes. Moreover, QDs of different compositions and the same light source can excite different sizes, resulting in unique emission colours over a wide spectrum of wavelengths. This property makes QDs particularly attractive for multiplex imaging. Extensive research has been conducted on the use of QDs as contrast agents for in vivo imaging and targeted drug delivery sensors in the medical field, as evidenced by numerous published studies [10]

According to the authors, these nanoparticles have a spherical shape and exhibit enhanced paclitaxel encapsulation efficiency, leading to increased suppression of tumour growth. The authors also claim that the method specifically targets and detects H22 tumour cells.
Carbon nanotubes are cylindrical molecules made up of rolled-up sheets of carbon atoms, specifically graphene. They can exist in two forms: multi-walled or single-walled, with the latter being composed of concentrically connected nanotubes. While pristine carbon nanotubes are completely insoluble in solvents, researchers are investigating their biological properties in terms of toxicity. However, the addition of strong acids can oxidize carbon nanotubes, resulting in shorter nanotubes with carboxylic groups that enhance their dispersibility in aqueous solutions. To functionalize the exterior walls of carbon nanotubes, a systematic method has been developed utilizing azomethine ylides in a 1,3 dipolar cycloaddition. In this procedure, carbon nanotubes are heated in N,N-dimethylformamide (DMF) with an alpha amino acid and an aldehyde. The resulting reaction yields functionalized carbon nanotubes (f-CNT) that exhibit high solubility in various solvents. By carefully selecting the reactants, researchers can modify the solubility of carbon nanotubes in organic solvents or aqueous solutions. Carbon nanotubes have demonstrated excellent solubility in water, making them attractive for potential applications in delivering therapeutic molecules.

5 Carbon nanotubes

5.1 Hydrogels

The hydrophilic groups make them a three-dimensional cross-linked network with significant swelling. Hydrogels have low immunogenicity, physical and chemical characteristics, are simple to operate, and are biocompatible. Hydrogels made of polysaccharides are particularly useful since they are naturally abundant, innately biodegradable, and renewable. Hydrogels have the capability to not only protect sensitive drugs from degradation but also serve as carriers for various therapeutic components. These components can include small molecule medications, hydrophobic and hydrophilic pharmaceuticals, growth factors, and inhibitors. One potential advancement in drug delivery systems (DDSs) involves the development of hydrogel nanocomposites incorporating nanoparticles, which can enhance the effectiveness of DDSs. Hydrogels exhibit diverse characteristics in terms of size, architecture, and physical properties, allowing them to mimic the controlled release of medications within the drug delivery system. Macroscopic hydrogels
are well-suited for transepithelial administration or injection, while hydrogel-forming microneedles have found extensive use in transdermal drug delivery. Hydrogels with micrometre-sized particles have also been utilized for oral and pulmonary administration of medications.[13]

Table 1. Applications of nanoparticles

<table>
<thead>
<tr>
<th>Modality</th>
<th>Potential application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilevers</td>
<td>High throughput screening&lt;br&gt;Gene expression detection</td>
</tr>
<tr>
<td>Carbon nanotubes</td>
<td>Gene mutation detection&lt;br&gt;Disease biomarker detection</td>
</tr>
<tr>
<td>Dendrimers</td>
<td>Image contrast agents</td>
</tr>
<tr>
<td>Nanoshell</td>
<td>Tumor specific imaging</td>
</tr>
<tr>
<td>Nano wires</td>
<td>Gene expression detection&lt;br&gt;Dna mutation detection</td>
</tr>
<tr>
<td>Nanocrystals</td>
<td>Improve formulation of poorly soluble drugs</td>
</tr>
<tr>
<td>Quantum dots</td>
<td>Tumour and lymph node visualization</td>
</tr>
</tbody>
</table>

6 Eradication of pathogens

6.1 Nanotechnology's impact on viral infection

Infectious diseases that are spreading around the world are the main reason for death. Viruses specifically have an impact on socioeconomic development and heath globally. The rapid development of drug resistance to a serious public health care concern is currently available therapies and adverse side effect due to prolonged use. The interlink age of nanostructures with microorganism is speedy transform. The unique property provided by nanoparticle is that they have their own benefits for drug delivery [14]
Salmonellosis has been on the rise in recent years, and more instances may have gone undetected or unreported. There are several different varieties of Salmonella; some of these cause illness in both humans and animals, while others exclusively affect animals and not people. Serotypes, which are closely related microorganisms that share specific structural characteristics, are the name given to the types of Salmonella that infect humans. Salmonella species are gram negative, anaerobic intracellular bacteria. Salmonella typhi, the primary cause of salmonellosis, infects HIV patients more frequently than a healthy individual would, and these people get bacteremia significantly more frequently. [15]

7 Covid-19 and cancer: mechanism of vaccine development by application of nanotechnology

7.1 Comorbidity of covid-19 and cancer

As further said, numerous experts have reached the conclusion that people with comorbidities are more likely than healthy people to die from the nasty SARS Cov-2 virus due to its "prime circumstances," which is why more patients die from these illnesses. According to the "Centers for Disease Control and Prevention," people of all ages who experience any kind of medical trauma are at an increased risk of developing COVID-19. These conditions include COPD, asthma, cancer, obesity, chronic kidney disease, serious heart conditions like heart failure and coronary artery disease, and diabetes (types 2), which can cause a severe reaction. According to a recent study, there are 2.5 million cancer patients in the United Kingdom, and
between 2015 and 2017 there were 367,167 new cases, the most of which are bowel, lung, breast, and blood cancers. [16][15]

Patients already have a very high chance of developing illnesses that are directly related to cancer. Obesity, diabetes, heart disease, dyslipidemia, hypertension, osteopenia, and osteoporosis are common cancer comorbidities.

Heart-related diseases such heart failure, arterial fribillation, and myocardial infarction are closely followed by hypertension and hyperlipidemia, which are reported to affect 70% and above 50% of people, respectively. It includes not only physical symptoms but also those of mental illnesses including major depressive disorder and anxiety disorders, which are both very common[17]

8 APPLICATIONS OF NANOTECHNOLOGY

We must concentrate on the molecular scale, which is regularly atom by atom, in the quickly developing field of nanotechnology in order to create and manage tools, materials, and functional systems with Nano metric dimensions. "Nanotechnological marvels" have been carried out by nature for millions of years. A short while ago, self-replicating, self-tracking, self-commanding, and self-mending devices, formations, and materials gave us the ability to discern nanoscale special tactics. Particularly in the areas of agriculture and food systems, authors have identified some problems, which are described along with some nanotechnology solutions.

![Fig.7. Heterogeneity of nanoparticles for treatment](image)

8.1 Microfluidics

At the microscopic level, fluid has the same viscosity as molasses when it flows through tiny channels. Despite the fact that other microfabricated channels were also used in the motion but did not mix (feature of laminar flow) [18].

Laminar flow, which operates at the microfluidic level, drives the alignment of residing cells in a single order and creates a new level of accuracy in microbiology. Numerous microfluidic applications have the potential to improve chastity, DNA control of concerned identifications, medicine delivery to simplify, and the extension of conventional methods for
animal reproduction using fertilisation outside the womb. Microfabricated fluids, often known as "lab-on-a-chip," are an identical component of everyday care. The technology of today allows for the chemical commanding of minute samples and its explanations.

![Image](https://example.com/image.png)

**Fig. 8.** Comparison between tradition medicine and nanovaccines.

### 8.2 Biomicro-electromechanical systems

Micro electro-mechanical (MEMS) or other small-scale machine construction techniques have been implemented. At the micro scale, there are pumps, sensors, totally effective pumps, rotors, and levers. The engineering novel defiance will be the progression from micro-sized to nano-sized devices of Nano electro mechanical systems (NEMS). Incorporating mounted MEMS technology with biological structures and microfluidics results in devices of a new class dubbed as "BIOMEMS" that would carry out functions at the nanoscale, such as collecting foreign antigen and delivering drugs to specific locations.[19]

### 8.3 Nucleic acid bioengineering with nanotechnology

These days, a lot of nanotechnology devices are made of silica dust and other materials that are obtained by removing the carving from the initial unit, or, to put it another way, by engraving the end structure. Genetic engineering, also known as nucleic acid engineering, refers to a tool that allows us to easily harness DNA molecules and produce a particular fashioned structure that will result in a new and larger structural unit. Nanowires and Nano membranes are two products these construction units are used to create[19]

Nanotechnology has brought about significant advancements in regenerative medicine and tissue engineering by introducing innovative approaches for tissue repair and regeneration. This field has been revolutionized by the integration of nanomaterial, which has enabled the creation of sophisticated scaffolds and matrices with improved structural and functional characteristics. Extensive research has been conducted on the capabilities of nanofibers, Nano composites, nanoparticles, and Nano gels to mimic the extracellular matrix, offering a high surface area-to-volume ratio and adjustable mechanical properties.
Furthermore, these nanomaterial can facilitate biological interactions by promoting cell adhesion, proliferation, and differentiation through the addition of bioactive chemicals and growth factors to their surfaces [20].

Nanotechnology has made a substantial contribution to the creation of regulated medication delivery systems in tissue engineering. For the prolonged and controlled release of growth factors, small compounds, and medicinal agents, polymeric nanoparticles and mesoporous silica nanoparticles have been widely used. By enabling localized and targeted delivery, these nanoparticles improve the effectiveness of tissue regeneration. Additionally, by utilizing active targeting mechanisms, functionalized nanoparticles have shown the potential for site-specific delivery, enabling the precise and effective delivery of therapeutic drugs to certain tissues or cells of interest. Additionally promising, magnetic nanoparticles provide for spatiotemporal modulation of therapeutic administration by remote drug release [10,16].

Nanotechnology methods have considerably benefited stem cell therapy. By directing stem cells’ differentiation pathways, Nano topography and surface modification techniques have been used to affect stem cell behaviour. Researchers can accurately control cellular adhesion, proliferation, and differentiation by modifying surface qualities at the Nano scale. Another intriguing approach to stem cell therapy is nanoparticle-mediated gene delivery, which enables effective and targeted gene delivery to stem cells using viral vectors or lipid-based carrier’s. With this strategy, personalized medicines can be created where certain genes can be added to increase stem cell development or advance desired cellular functions.

The creation of nanomaterial-based scaffolds for stem cell transplantation depends heavily on nanotechnology. The three-dimensional (3D) environment that these scaffolds offer encourages stem cell adhesion, proliferation, and differentiation. Nanomaterial with special structural and functional qualities, like nanofibers, Nano composites, and hydrogels, closely mirror the extracellular matrix in nature. A biomimetic microenvironment is created when the scaffold surface is functionalized with bioactive chemicals and growth factors. This improves stem cell adhesion and directs their differentiation process. An effective platform for the controlled distribution of signals to stem cells, promoting their integration into the target tissue, is provided by this combination of nanotechnology and scaffolding techniques [21].

The potential of nanotechnology in regenerative medicine is shown by a variety of preclinical and clinical applications. For instance, bone regeneration, cardiac tissue engineering, and nerve regeneration have all shown promise when using nanomaterial-based scaffolds. To guarantee the safety and effectiveness of these medicines, however, issues including long-term biocompatibility, scalability, and regulatory considerations must be resolved [22].

8.4 Nanotechnology in Stem Cell Therapy

In the realm of stem cell therapy, nanotechnology has become a formidable tool that presents uncommon prospects to improve stem cell behavior and their therapeutic potential. Nanotechnology allows for precise control over stem cell proliferation, differentiation, and transplantation by taking advantage of the characteristics of nanoparticles and nanomaterial. This article gives a general overview of how nanotechnology is used in stem cell therapy, highlighting significant developments and their prospective effects.

Influencing stem cell behavior is one important area where nanotechnology has significantly benefited stem cell therapy. To direct stem cell differentiation pathways and
direct their fate, nan topography and surface modification approaches have been used (Sridhar et al., 2020). Researchers can affect cellular adhesion, proliferation, and differentiation by modifying surface characteristics at the Nano scale, such as roughness or chemical composition. These Nano scale signals provide exact control over stem cell behavior by simulating the organic cellular microenvironment.[20]

In addition to surface alterations, stem cells can be precisely programmed and behaved by being given access to bioactive chemicals and genetic resources via nanotechnology. A particularly promising strategy in stem cell therapy is nanoparticle-mediated gene delivery. Targeted and effective gene delivery to stem cells can be accomplished by encapsulating genetic materials within nanoparticles, such as viral vectors or lipid-based carriers. The use of particular genes to promote particular cellular activities or to improve stem cell differentiation allows for personalized therapeutics.

The creation of nanomaterial-based scaffolds for stem cell transplantation depends heavily on nanotechnology. The three-dimensional (3D) environment that these scaffolds offer encourages stem cell adhesion, proliferation, and differentiation. [21]

Nanomaterials with special structural and functional qualities, like nanofibers, nanocomposites, and hydrogels, closely mirror the extracellular matrix in nature. In order to improve stem cell adhesion and direct their differentiation process, the surface of these scaffolds can be functionalized with bioactive molecules and growth factors. This hybrid of scaffolding methods and nanotechnology offers a platform for the precise signal transmission to stem cells while simulating the intricate cellular material.

**Fig. 9.** Different applications of Nano system
The clinical application of stem cell therapies based on nanotechnology is a current topic of study and development. Numerous preclinical and clinical investigations have shown that nanotechnology has the potential to enhance stem cell-based therapies. For instance, nanomaterial-based scaffolds have demonstrated promising outcomes in the regeneration of nerves, cardiac tissue, and bone. To guarantee the safety and effectiveness of these medicines,
however, issues including long-term biocompatibility, scalability, and regulatory considerations must be resolved.[21]

Finally, nanotechnology offers useful instruments and strategies for developing stem cell treatment. New opportunities for regenerative medicine arise from the capacity to control stem cell behavior via controlled delivery of bioactive chemicals, surface changes, and nanotopography[22]

![Fig. 10. Process of preparation of Nano vaccines from Nano particles.](image)

### 9 POTENTIAL RISK OF TECHNOLOGIES

Despite capturing the interest of the general public, nanotechnology, an area of rapid development, has sparked considerable debates regarding its safety and potential health risks. The use of nanoparticles creates additional difficulties for anticipating, comprehending, and successfully addressing possible health issues. Research indicates that low-solubility nanoparticles are more hazardous and toxic compared to larger particles when considering mass-to-mass ratio. Nanoparticles also bring forth the risks of explosions and catalytic reactions. It is crucial to remember that only a select class of nanomaterial—particularly those with high reactivity and mobility—are regarded as dangerous. Even just having nanomaterial around in a lab environment does not pose a concern to individuals or the ecosystem, unless comprehensive investigations reveal their harmful effects[23]

### 10 Conclusion

Certainly, the advancement of nanotechnologies has undeniably facilitated significant advancements in the fields of biotechnology, pharmaceuticals, and medicine, resulting in an enhanced quality of life for patients. These nanotechnologies have proven to be beneficial in numerous aspects of healthcare, such as diagnosis, therapeutic interventions, and monitoring of patients' progress. Efforts are continuously being made to produce and advance state-of-the-art nanomaterial with the aim of improving diagnostics, ultimately leading to more personalized, cost-effective, and safe medical procedures. Furthermore, nanotechnologies are being utilized to develop targeted, accurate, potent, and long-lasting therapies for various diseases.
11 Future Perspective

1. Multifunctional Nano devices: Personalized medicine holds enormous promise for the development of multifunctional Nano devices that can carry out numerous activities at once, such as targeted drug delivery, imaging, and therapy.
2. Nano sensors and Diagnostics: nanotechnology holds the promise of developing highly sensitive and selective Nano sensors for the early diagnosis and detection of disease.
3. Nano-Immunotherapy: the development of immunotherapies to improve immune responses against cancer and infectious illnesses is being investigated using nanotechnology-based techniques, including nanoparticles and nanostructured materials.
4. Tissue Engineering and Regenerative Medicine: By enabling the development of functional and biomimetic constructions for tissue repair and organ regeneration, nanomaterial’s and nanofabrication techniques have the potential to revolutionize these fields.

12 New Challenges and Approaches

There is promise for Nano sized drug delivery systems for herbal treatments to enhance biological activity and circumvent drawbacks of plant-based therapeutics. Nevertheless, there are still several challenges in this area to implementing clinically viable treatments. The present challenges in translating this technology into treatments include testing novel methods to control how nanoparticles interact using biological systems. The creation of medication delivery systems based on nanotechnology confronts new challenges, such as the potential for obtaining multifunctional systems to satisfy various biological and therapeutic requirements and the viability of scale-up processes that quickly bring innovative therapeutic techniques to market. More recent issues include determining the targeting efficiency of nanoparticles and achieving international standards for their toxicity and biocompatibility.

References

3. Y. Liu, G. Yang, Y. Hui, S. Ranaweera, and C. X. Zhao, Small 18, 1 (2022)
7. K. Jagadeesh Chandra Bose and J. Sarwan, Nanovaccinology 79 (2023)


20. X. Tan, F. Jia, P. Wang, and K. Zhang, (n.d.)

