

Revolutionizing Medicine: The Impact Of Nano-Engineered Drug Delivery Systems

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Abstract

The increasing occurrence of diseases and illnesses has emphasized the immediate need for precise and effective medication delivery systems to efficiently treat illnesses and enhance individual health. Traditional types of medicine have intrinsic limitations, such as brief periods of effectiveness, low patient compliance, and variable drug concentrations. As a reaction, modified and targeted-release dose formulations have developed as a possible option. Nano-engineered drug delivery systems have attracted considerable interest because of their ability to target particular sites, regulate medication release, and improve patient compliance. This paper examines the significant impact of nanotechnology on medication delivery methods. The text explores many categories of nanoparticles, such as polymeric nanoparticles, liposomes, dendrimers, and metal nanoparticles, and their unique chemical and physical characteristics. Nanoparticles provide benefits such as a high surface area-to-volume ratio, precise medication delivery to particular cells or tissues, enhanced drug stability, and regulated release kinetics. The study emphasizes the use of nanoparticles in the field of medication delivery, namely in the areas of cancer treatment, gene therapy, and immunization. Nanoparticles have the ability to specifically focus on tumor cells, so improving the effectiveness of drugs while reducing the harmful effects on the whole body. Furthermore, they facilitate the transportation of therapeutic genes and nucleic acids to precise cells, presenting promise in the field of gene therapy. In addition, nanoparticles have the capability to augment the immune response by efficiently delivering antigens throughout the process of vaccination. Ultimately, nano-engineered drug delivery systems has the capacity to transform the field of medicine by surpassing the constraints of traditional drug formulations. Nanotechnology's incorporation into medication delivery shows potential for enhancing treatment efficacy, reducing adverse effects, and facilitating the development of customized medicine.

Keywords: nano-engineered drug delivery systems, nanoparticles, targeted drug delivery, controlled release, nanotechnology.

1. Introduction

Because of the worrying rise in the number of diseases and illnesses, it is now more important than ever to find the right targeted dosage form in order to manage the illness and enhance the individual's health (Rajan et al., 2022). The traditional medication form has numerous

drawbacks, such as the repetitive management of a medication with a shorter half-life, reduced adherence among patients, high peak, and common peak–valley plasma concentration–time description, etc., as a result, it is not possible to get a steady-state drug concentration or particularity of targeting. As a result of these drawbacks, a new dose form that was changed and geared at a certain population emerged. The traditional dose form is being gradually replaced by their altered and targeted-release form of administration. This transition is taking place relatively slowly (Sur et al., 2019).

Due to its site-specificity, controlled drug release, and better adherence by patients, customized and customized drug delivery systems are in great demand. These systems deliver medications to the intended location. Polymers are thought of as the structural foundation when it comes to the process of building a system for the distribution of altered or targeted medications (Sivadasan et al., 2021). A biocompatible polymer has seen enormous development as a result of the additional benefit it provides, and as a result, it is the issue that everyone is talking about right now. Colloidal particles that fall within the range of 1 to 100 nm in size and are referred to as nanoparticles are able to deliver drugs in a specific way (Pirtarighat et al., 2019).

The term "nano" originates from the Greek word "nanos," which literally translates as "very dwarf." (Sur et al., 2019). Polymeric, carbon-based, semiconductor, metal, lipid-based, and ceramic nanoparticles are some examples of the many kinds of nanoparticles that may be classified according to their shape, as well as their chemical and physical characteristics. Out of these, polymeric nanoparticles are the subject of the most study because of the benefits that they have beyond others (Khan and Hossain, 2022). Additionally, this is owing to the progress that has been made in polymer science and nanotechnology, since polymeric nanoparticles have seen a significant amount of improvement. Polymeric nanoparticles provide a number of benefits, including a straightforward fabrication process, a size distribution that is simple to manage, excellent drug preservation, and safeguarding, among other benefits (Kurian et al., 2022; Sen et al., 2023).

Nanotechnology is a multifaceted field of science and engineering that handles designing, making, and manipulating things at the nanoscale stage. Nanotechnology could change the way drugs are given to patients in the field of drug delivery, which is one of its most hopeful fields of use (Contera, 2019). Nanoparticles can be used to encase drugs, keep them from breaking down, and send them to specific places in the body. This makes the drugs work better and makes them less harmful. When nanotechnology is used to transport drugs, they can be sent to specific cells or organs. This improves the effectiveness of the treatment and reduces side effects (Pramanik et al., 2020; Joseph et al., 2023). This review piece tries to give a description of how nanotechnology is used in drug delivery systems. It will talk about the various kinds of nanoparticles, their qualities, how they are used in drug delivery, recent improvements, and what the future holds for nanotechnology in drug delivery systems.

2. Outline of Drug Delivery Systems

Drug delivery systems (DDS) are devices that are made to make drugs work better and be safer for patients. DDS can be put into different groups based on how it is given, such as orally, topically, intravenously, or through the lungs (Jain, 2020). Different DDS, such as liposomes, nanoparticles, and dendrimers, can be used to improve the drug delivery process based on how the drug is given (Aguilar-Pérez et al., 2020). Nanoparticles-based DDS have been studied a lot in the last few decades because they have unique qualities, such as a high ratio of surface area to volume, a small size, and reactive surfaces. Nanoparticles can be made to hold drugs inside their core or shell. This keeps the drugs from breaking down and makes them easier to dissolve and absorb. Also, nanoparticles can be made to target specific cells or tissues. This

means that less of the drug is needed to have a beneficial effect and that there is less damage to other parts of the body (Wani et al., 2022; Pourmadadi et al., 2023).

3. Types of Nanoparticles

There are different kinds of nanoparticles, such as liposomes, dendrimers, polymeric nanoparticles, and metal nanoparticles. Liposomes are circular spheres made of a double layer of phospholipids. They can hold both drugs that dissolve in water and those that don't. Dendrimers are polymers that have a lot of branches and can be made to have a certain size, shape, and surface qualities. Polymeric nanoparticles are made up of organic polymers that can hold drugs and slowly release them. Inorganic nanoparticles like gold, silver, and iron oxide nanoparticles have unique visual, magnetic, and electronic qualities that can be used to deliver drugs (Figure 1). For inactive or active drug addressing, numerous variations have been looked into do a great job of reviewing this topic for lipid nanoparticles (Desfrancois et al., 2018). For example, wrapping nanoparticles with chemicals that don't like water, like polyoxamer, polysorbate 80 (Tween 80), PEG, and poloxamine, is linked to a longer time in circulation and less uptake. Nanoparticles can also be modified with peptides, antibodies, saccharides (hyaluronic acid, mannose), and transferrins so that the target ligand and nanoparticle conjugates can combine in a particular way (Silva et al., 2019).



Figure 1. Different types of nanoparticles (Silva et al., 2019).

4. Properties of Nanoparticles

When contrasted to the bulk equivalents that they are manufactured from, new particles have certain properties that are distinctively their own. These features involve but aren't restricted to, extraordinarily large surface areas; great reactivities; remarkable mobilities; superior chemical, electrical, and mechanical characteristics; and remarkable mobility. On the other hand, it is a fact that the characteristics of certain nanoparticles are very reliant on the particle size as well as the substance that the nanoparticles were generated. Because of this, it is apparent that certain nanoparticles exhibit outstanding magnetic, optical, or electrical capabilities, whereas other kinds of nanoparticles do not have these qualities (Sur et al., 2019; Sajid and Plotka-Wasyłka, 2020).

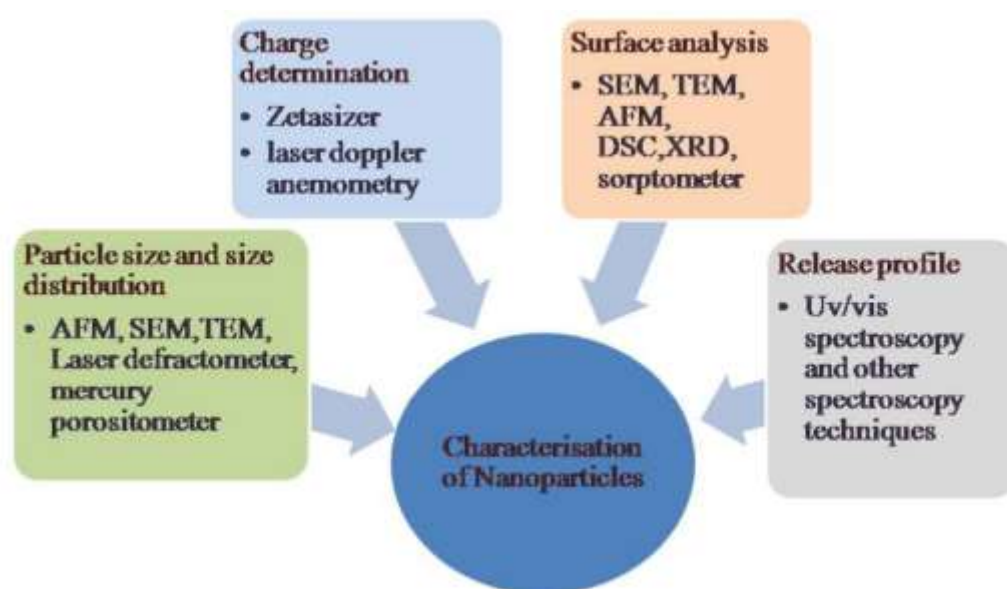


Figure 2. Characteristics of nanoparticles (Sur et al., 2019).

Nanoparticles have a lot of characteristics that make them an appropriate option for drug delivery. First, they have a high amount of surface area to volume, which means they can hold more drugs. Second, they can be made to work with ligands that target cells or tissues, like antibodies or peptides. This makes it possible to target specific cells or tissues. Third, they can keep drugs from breaking down and leaving the body, which lets them stay in circulation longer. Lastly, they can be made to release drugs in a controlled way, which lets the drugs stay in the body for a long time (Masunga et al., 2019).

5. Applications of Nanoparticles in Drug Delivery

Products based on nanotechnology are becoming more valuable in the field of medicine, which has resulted in the development of innovative nanosystems for the diagnosis, imaging, and treatment of a wide range of illnesses (Prajnamitra et al., 2019). Some of these diseases include cancer, cardiovascular disease, eye disease, and disorders connected to the central nervous system. Nanomaterials are able to be successfully integrated into biomedical devices since the majority of biological structures are also nanosized (Javed et al., 2020). In the realm of drug delivery, nanosystems allow the exact delivery of pharmaceuticals to the target organs or tissues with a regulated release and extended retention duration as compared to traditional

procedures. In addition, nanosystems give these benefits in a shorter amount of time. Nano-liposomes are one of the greatest examples of nanosystems that are currently being investigated for specific drug delivery for the treatment of many forms of cancer and cardiovascular illnesses (Khan et al., 2020). Nano-liposomes are used for a variety of reasons, the most important of which are the delivery of drugs to specific tissues, their high level of biocompatibility, and the ability to regulate the flow of drugs through circulation (Hatami et al., 2021).

Nanoparticles can be used to directly target tumor cells in cancer treatment. This means that there can be higher drug amounts at the tumor site and less overall damage. For instance, liposomes have been used to package chemotherapy drugs like doxorubicin and paclitaxel, which are then directed to tumor cells using ligands on their surfaces. In the same way, antibodies have been added to gold nanoparticles so that they can target specific cancer cells and deliver drugs like cisplatin or docetaxel.

In gene therapy, nanoparticles can send nucleic acids like DNA or RNA to specific cells. This makes it possible for healing proteins to be made or for genes that cause disease to be turned off. For example, polymeric nanoparticles have been used to send siRNA to cancer cells to turn off oncogenes. In the same way, DNA or RNA has been added to gold nanoparticles to send genes to specific cells (Anjum et al., 2021).

Nanoparticles can be used to deliver antigens to immune cells during vaccination. This boosts the immune reaction and makes the vaccine more effective. For example, liposomes have been used to send antigens to dendritic cells, which then stimulate T cells and start an immunological reaction. Polymeric nanoparticles have also been used to send antigens to B cells and cause them to make antibodies. Figure 3 presents a synopsis of the primary areas of medicine in which nanosystems mediated by nanotechnology (Theobald, 2020; Liu et al., 2021).

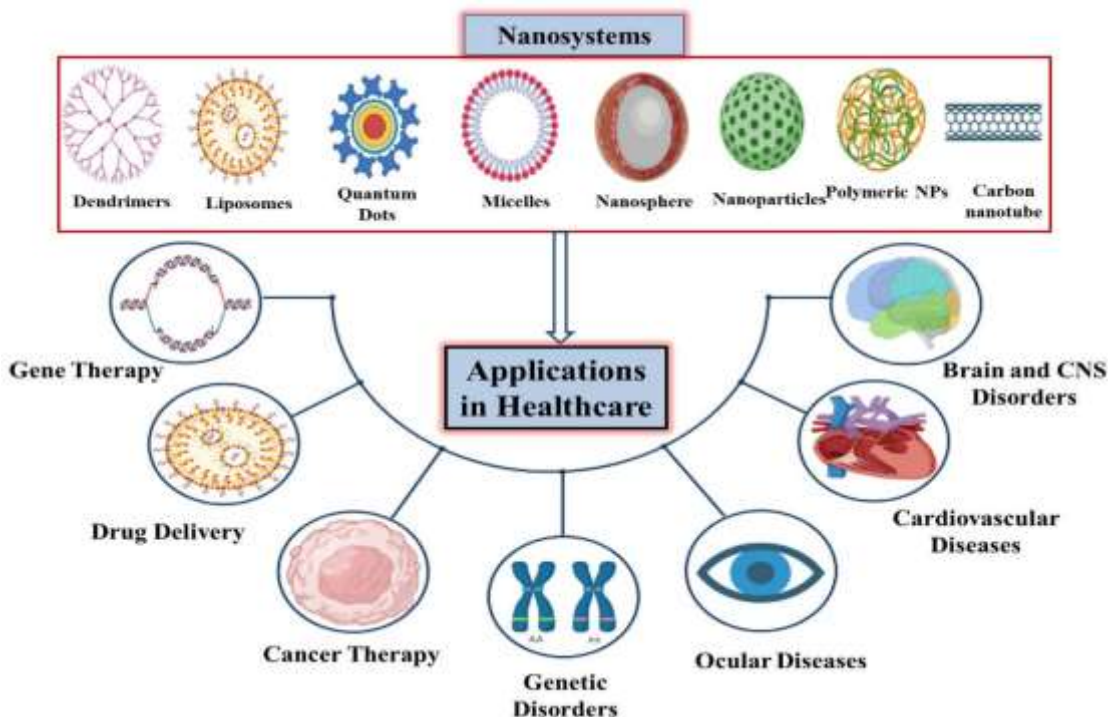


Figure 3. Different applications of nanoparticles (Anjum et al., 2021).

6. Challenges and Future Directions:

There are still many obstacles to overcome in the field of medication delivery despite the promise that nanoparticles provide. To begin, nanoparticles are capable of causing toxicity as well as immunological responses, which restricts their use in therapeutic settings. Second, there are still obstacles to overcome in order to achieve particular targeting of cells or tissues, since nanoparticles might be eliminated by the body before they reach their destination. Thirdly, the intricate synthesis and characterisation of nanoparticles may be a time- and money-consuming process that can be rather costly. The creation of nanoparticles that are more biocompatible and biodegradable is one of the future objectives in the area of nanotechnology in drug delivery. Other future avenues include the use of nanotechnology to personalized medicine and the integration of nanotechnology with other technologies like as imaging and sensing. In addition, for there to be progress made in nanotechnology, researchers from other domains, such as chemistry, materials science, and biomedical engineering, will need to work together.

7. Conclusion

Nanoparticles have the possibility to completely alter drug delivery methods by enabling the targeted distribution of medications to certain cells or tissues, hence increasing the therapeutic effectiveness while simultaneously minimizing the number of adverse effects. Various nanoparticles, such as liposomes, dendrimers, polymeric nanoparticles, and inorganic nanoparticles, each have their own unique features that may be used in the process of drug administration. Despite the fact that there are still obstacles to overcome, the area of nanotechnology in drug delivery is making significant progress, which presents many exciting prospects for the future of medicine.

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