Nano-engineered drug delivery systems: Transforming the landscape of medicine

Mahir A. Jalal
Chemistry and Polymer Technology
Polymer Research Center University of Basrah
mahir.jalal@uobasrah.edu.iq
Alyaa Abdul Hasan Abdul Karem
Chemistry and Polymer Technology
Polymer Research Center University of Basrah
Alyaa.abdulkarem@uobasrah.edu.iq
E.H. Al-Tememe
Pharmacy College
University of Basrah
Iraq

DOI Number: 10.48047/nq.2024.22.3.NQ24009 **NeuroQuantology 2024; 22(3):74-81**

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 (Desfrançois et al.,2018). For example, wrapping nanoparticles with chemicals that don't like water, like polyoxamer, polysorbate 80 (Tween 80), PEG,andpoloxamine, is linked to a longer time in circulation and less uptake. Nanoparticles can also be modified with peptides, antibodies, saccharides (hyaluronic acid, mannose), and transferrinsso that the target ligand and nanoparticle conjugates can combine in a particular way(Silva et al., 2019).

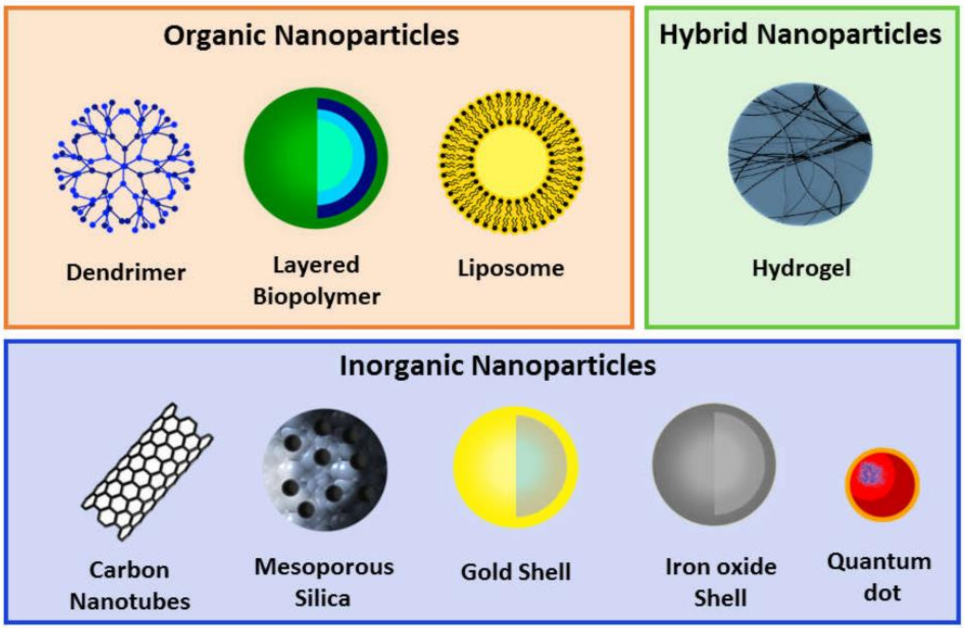
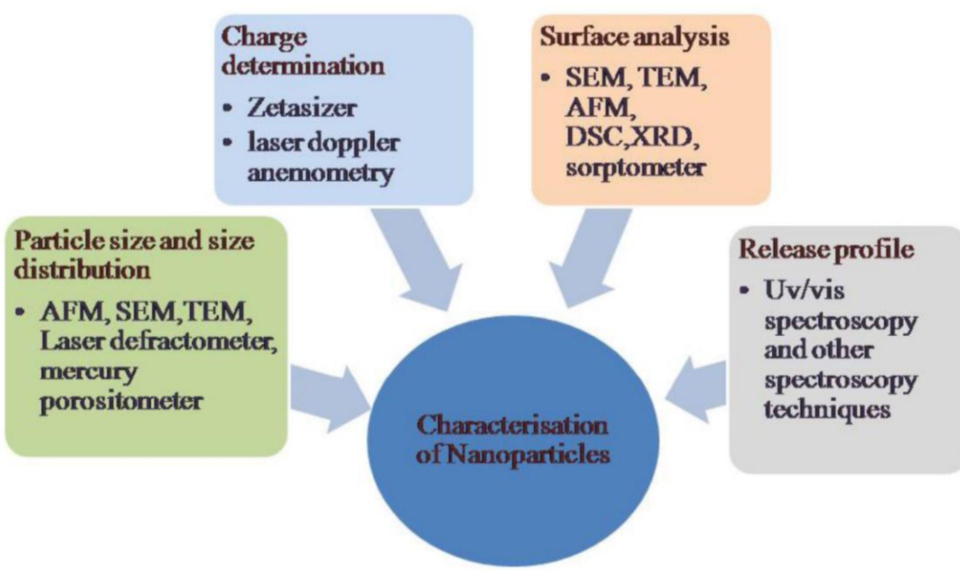


Figure 1. Different types of nanoparticles(Silva et al., 2019).

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 andPłotka-Wasylka, 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).

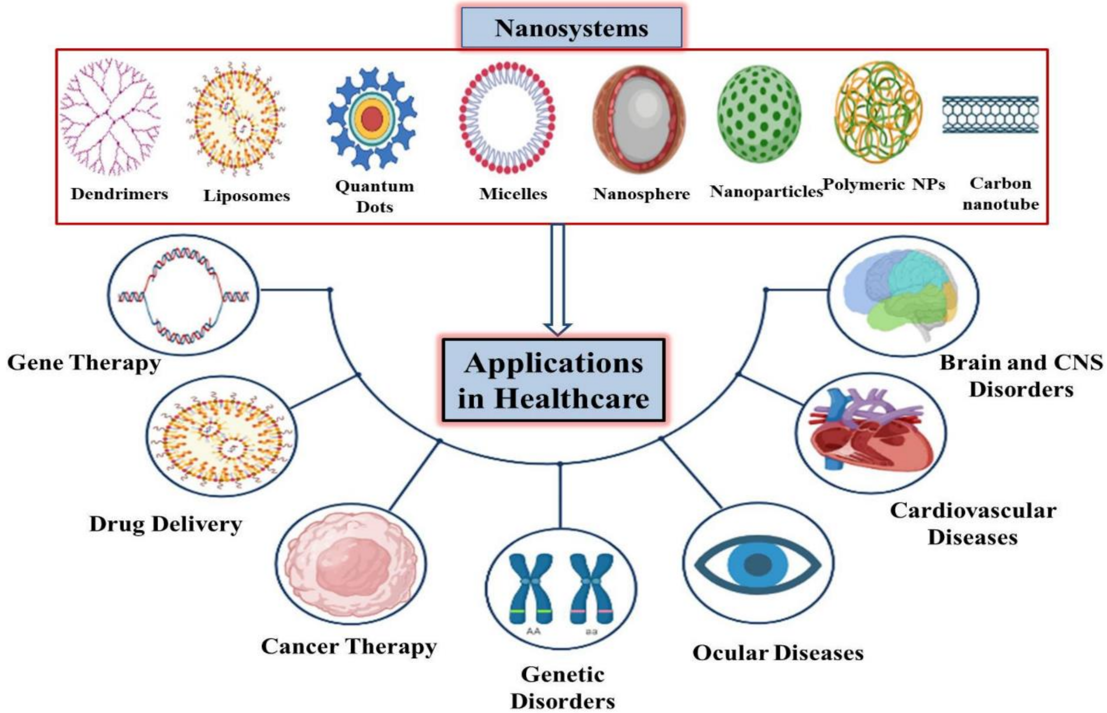


Figure 3. Different applications of nanoparticles(Anjum et al., 2021).

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.

References

1. Aguilar-Pérez, K. M., Avilés-Castrillo, J. I., Medina, D. I., Parra-Saldivar, R., & Iqbal, H. M. (2020). Insight into nanoliposomes as smart nanocarriers

for greening the twenty-first century biomedical settings. *Frontiers in Bioengineering and Biotechnology*, *8*, 579536.

2. Anjum, S., Ishaque, S., Fatima, H., Farooq, W., Hano, C., Abbasi, B. H., & Anjum, I. (2021). Emerging applications of nanotechnology in healthcare systems: Grand challenges and perspectives. *Pharmaceuticals*, *14*(8), 707.
3. Contera, S. (2019). *Nano comes to life: How nanotechnology is transforming medicine and the future of biology*. Princeton University Press.
4. Desfrançois, C., Auzély, R., &Texier, I. (2018). Lipid nanoparticles and their hydrogel composites for drug delivery: a review. *Pharmaceuticals*, *11*(4), 118.
5. Hatami, A., Heydarinasab, A., Akbarzadehkhiyavi, A., &Pajoum Shariati, F. J. C. M. (2021). An introduction to nanotechnology and drug delivery. *Chem. Methodol*, *5*, 153-165.
6. Jain, K. K. (2020). An overview of drug delivery systems. *drug delivery systems*, 1-54.
7. Javed, R., Zia, M., Naz, S., Aisida, S. O., Ain, N. U., &Ao, Q. (2020). Role of capping agents in the application of nanoparticles in biomedicine and environmental remediation: recent trends and future prospects. *Journal of Nanobiotechnology*, *18*, 1-15.
8. Joseph, T. M., Kar Mahapatra, D., Esmaeili, A., Piszczyk, Ł., Hasanin, M. S., Kattali, M., ... & Thomas, S. (2023). Nanoparticles: Taking a unique position in medicine. *Nanomaterials*, *13*(3), 574.
9. Khan, A. U., Khan, M., Cho, M. H., & Khan, M. M. (2020). Selected nanotechnologies and nanostructures for drug delivery, nanomedicine and cure. *Bioprocess and biosystems engineering*, *43*, 1339-1357.
10. Khan, S., & Hossain, M. K. (2022). Classification and properties of nanoparticles. In *Nanoparticle-based polymer composites* (pp. 15-54). Woodhead Publishing.
11. Kurian, A. G., Singh, R. K., Patel, K. D., Lee, J. H., & Kim, H. W. (2022). Multifunctional GelMA platforms with nanomaterials for advanced tissue therapeutics. *Bioactive materials*, *8*, 267-295.
12. Liu, G., Zhu, M., Zhao, X., &Nie, G. (2021). Nanotechnology-empowered vaccine delivery for enhancing CD8+ T cells-mediated cellular immunity. *Advanced Drug Delivery Reviews*, *176*, 113889.
13. Masunga, N., Mmelesi, O. K., Kefeni, K. K., & Mamba, B. B. (2019). Recent advances in copper ferrite nanoparticles and nanocomposites synthesis, magnetic properties and application in water treatment. *Journal of Environmental Chemical Engineering*, *7*(3), 103179.
14. Pirtarighat, S., Ghannadnia, M., &Baghshahi, S. (2019). Green synthesis of silver nanoparticles using the plant extract of Salvia spinosa grown in vitro and their antibacterial activity assessment. *Journal of Nanostructure in Chemistry*, *9*, 1-9.
15. Pourmadadi, M., Eshaghi, M. M., Ostovar, S., Mohammadi, Z., Sharma, R. K., Paiva-Santos, A. C., ... & Pandey, S. (2023). Innovative nanomaterials for cancer diagnosis, imaging, and therapy: Drug deliveryapplications. *Journal of Drug Delivery Science and Technology*, 104357.
16. Pramanik, P. K. D., Solanki, A., Debnath, A., Nayyar, A., El-Sappagh, S., & Kwak, K. S. (2020). Advancing modern healthcare with nanotechnology, nanobiosensors, and internet of nano things: Taxonomies, applications,

architecture, and challenges. *IEEE Access*, *8*, 65230-65266.

17. Prajnamitra, R. P., Chen, H. C., Lin, C. J., Chen, L. L., & Hsieh, P. C. H. (2019). Nanotechnology approaches in tackling cardiovascular diseases. *Molecules*, *24*(10), 2017.
18. Rajan, R., Pal, K., Jayadev, D., Jayan, J. S., U, A., Appukuttan, S., ... & Kumar, S. S. (2022). Polymeric nanoparticles in hybrid catalytic processing and drug delivery system. *Topics in Catalysis*, *65*(19-20), 1860-1884.
19. Abd Algani, Y. M., Caro, O. J. M., Bravo, L. M. R., Kaur, C., Al Ansari, M. S., &Bala, B. K. (2023). Leaf disease identification and classification using optimized deep learning. *Measurement: Sensors*, *25*, 100643.
20. J. K. S. Al-Safi, A. Bansal, M. Aarif, M. S. Z. Almahairah, G. Manoharan and F. J. Alotoum, "Assessment Based On IoT For Efficient Information Surveillance Regarding Harmful Strikes Upon Financial Collection," 2023 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 2023, pp. 1-5, doi: 10.1109/ICCCI56745.2023.10128500.
21. Kaur, C., Kumar, M. S., Anjum, A., Binda, M. B., Mallu, M. R., & Al Ansari, M. S. (2023). Chronic kidney disease prediction using machine learning. *Journal of Advances in Information Technology*, *14*(2), 384-391.
22. Eadline, D. (2015). *Hadoop 2 Quick-Start Guide: Learn the Essentials of Big Data Computing in the Apache Hadoop 2 Ecosystem*. Addison-Wesley Professional.
23. M. A. Tripathi, R. Tripathi, F. Effendy, G. Manoharan, M. John Paul and M. Aarif, "An In-Depth Analysis of the Role That ML and Big Data Play in Driving Digital Marketing's Paradigm Shift," 2023 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 2023, pp. 1-6, doi: 10.1109/ICCCI56745.2023.10128357.
24. Khan, S. I., Kaur, C., Al Ansari, M. S., Muda, I., Borda, R. F. C., &Bala, B. K. (2023). Implementation of cloud based IoT technology in manufacturing industry for smart control of manufacturing process. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 1-13.
25. Sajid, M., &Płotka-Wasylka, J. (2020). Nanoparticles: Synthesis, characteristics, and applications in analytical and other sciences. *Microchemical Journal*, *154*, 104623.
26. Sen, S., Xavier, J., Kumar, N., Ahmad, M. Z., & Ranjan, O. P. (2023). Exosomes as natural nanocarrier-based drug delivery system: recent insights and future perspectives. *3 Biotech*, *13*(3), 101.
27. Silva, S., Almeida, A. J., & Vale, N. (2019). Combination of cell-penetrating peptides with nanoparticles for therapeutic application: a review. *Biomolecules*, *9*(1), 22.
28. Sivadasan, D., Sultan, M. H., Madkhali, O., Almoshari, Y., &Thangavel, N. (2021). Polymeric lipid hybrid nanoparticles (plns) as emerging drug delivery platform—A comprehensive review of their properties, preparation methods, and therapeutic applications. *Pharmaceutics*, *13*(8), 1291.
29. Sur, S., Rathore, A., Dave, V., Reddy, K. R., Chouhan, R. S., & Sadhu, V. (2019). Recent developments in functionalized polymer nanoparticles for efficient drug delivery system. *Nano-Structures& Nano-Objects*, *20*, 100397.
30. Theobald, N. (2020). Emerging vaccine delivery systems for COVID-19: Functionalised silica nanoparticles offer a potentially safe and effective alternative delivery system for DNA/RNA vaccines and may be useful in

the hunt for a COVID-19 vaccine. *Drug Discovery Today*, *25*(9), 1556.

31. Wani, S. U. D., Ali, M., Masoodi, M. H., Khan, N. A., Zargar, M. I., Hassan, R., ... & Osmani, R. A. M. (2022). A review on nanoparticles categorization, characterization and applications in drug delivery systems. *Vibrational Spectroscopy*, *121*, 103407.