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Advancements in Nanotechnology for Drug Delivery Systems

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ABSTRACT

Nanotechnology has revolutionized drug delivery systems (DDS) by offering innovative approaches to enhance the efficacy and precision of therapeutic interventions. The field has enabled the design and development of nanocarriers, including liposomes, dendrimers, and polymeric nanoparticles, which have demonstrated significant potential in improving drug solubility, bioavailability, and targeted delivery. This paper explores the fundamentals of nanotechnology as applied to drug delivery, the various types of nanoparticles utilized, and their applications in targeting complex diseases like cancer. Despite the remarkable progress, challenges such as non-specific uptake, systemic side effects, and manufacturing scalability persist. Ongoing research aims to refine nanocarrier design and optimize production processes to overcome these barriers, paving the way for the next generation of nanomedicine.

Keywords: Nanotechnology, Drug Delivery Systems, Nanocarriers, Liposomes, Dendrimers.

INTRODUCTION

Nanotechnology refers to the manipulation of matter on a molecular scale, typically within the range of 1 to 100 nanometers. It can involve the design of an entirely new structure, the alteration of the properties of an already existing structure, or both. Another closely related term is nanomedicine, which is medical intervention involving nanotechnology. For drug delivery systems (DDS), nanotechnology has potential applications for new drug design, drug stabilization, new modes of action, drug targeting, and drug release [1, 2]. Nanocarrier systems have been successfully applied in delivering poorly soluble drugs. In recent years, there has been continuous effort from scientists in academia and the pharmaceutical industries in the area of drug delivery systems. Several studies and products utilizing nanotechnology have been implemented in clinical practices. To meet the clinical demand, various drug delivery systems have been designed and developed. Several successful nanocarriers, including dendrimers, nanoparticles, liposomes, and carbon nanotubes, among others, have been commercialized. Recently, the FDA approved their first nanodrug, Doxil™, for the treatment of cancer. Currently, there are more than 130 nanotechnology-based drug delivery products that have been commercialized or are undergoing clinical trials. Moreover, there are several ongoing clinical trials on using nanocarriers for the encapsulation of drug molecules or therapeutic agents. Numerous clinical trials are expected to propel the advancement of novel nanotherapeutics [3].

FUNDAMENTALS OF NANOTECHNOLOGY IN DRUG DELIVERY SYSTEMS

Nanotechnology has gained significant attention in recent years, particularly in biomedical applications. With a variety of constituent materials and fabrication methods, the flexibility of nanotechnology as a research field has allowed for the advancement of technologies, the establishment of markets, and the potential application of innovative products across a diverse array of disciplines. As society faces challenges such as an aging population, environmental pollution, energy shortages, and a growing wealth gap, nanotechnology is expected to play an important role in addressing such issues. Furthermore, new problems such as biological attacks, synthetic drug manufacturing by non-state actors, and the continued emergence of new infectious diseases require increased focus on bioarray and sensor technologies, drug

development, and prevention. With a variety of constituent materials and fabrication methods, the flexibility of nanotechnology as a research field has allowed for the advancement of technologies, the establishment of markets, and the potential cross-disciplinary application of innovative products [4, 5]. The principles of nanotechnology, as applied to drug delivery systems, are complex and diverse. Originally, drug delivery systems evolved from a simple drug administration with minimal side-effects to complicated systems with fewer side-effects but also with a complex formulation. Systems that treat diseases like cancer often do so with the most success after gaining a comprehensive understanding of the disease. However, for drug delivery systems, a full understanding of how drugs interact with the body, particularly with the close-to-target tissue, is difficult to attain. As such, drug delivery relies on the best efforts of the researcher's ingenuity and creativity in optimizing the formulation. While every component in a drug delivery system is designed to enhance a certain aspect of the change from simple drug to costly drug product, it is increasingly evidenced that nanoparticles in the system, either deliberately or not, affect many processes in the body with consequences for the design of the drug delivery system [6].

TYPES OF NANOPARTICLES USED IN DRUG DELIVERY

Liposomes are a good example of these nanoparticles, which are spherical vesicles formed by a phospholipid bilayer membrane surrounding an aqueous core. Drugs, either in a free form or conjugated with anti-cancer antibodies, can be incorporated inside the liposomes. Liposomes have shown improved drug bio-distribution and therapeutic efficacy with reduced systemic toxicity. Doxil, a liposomal formulation of doxorubicin for cancer therapy, has been used for cancer treatment in clinic, and other liposomal drugs are also under clinical investigation [7, 8]. Dendrimers are another type of nanoparticles that have a branched polymer architecture with a central core, repeated branching units, and terminal functional groups. To change their physicochemical properties, dendrimers can be chemically modified by altering either the branching unit or the terminal functional groups. They are of interest in drug delivery systems mainly because of their high drug loading capacity and tunable properties determined by size, shape, and surface functional groups. Moreover, the multivalency of dendrimers can form non-covalent or covalent complexes with drug molecules. For instance, using a simple hydrophobic drug-conjugated dendrimer approach, the drug release kinetics can be illustrated by the fact that doxorubicin-conjugated generation-4 PAMAM dendrimers show a greater retention effect when compared to an equal concentration of free doxorubicin molecule in vitro [9]. Polymeric nanoparticles (typically <1μm) can be classified as nanocapsules or nanospheres depending on their characteristics. Nanocapsules consist of a liquid core section surrounded by a solid polymeric shell, while nanospheres contain a solid core without an encapsulating shell. Biodegradable polymers are typically used in the delivery system design involving nanocapsules. Overall, polymeric nanoparticles possess a large number of advantages in drug delivery: controlled drug release and blood circulation, substantial reduction in toxicity if designed correctly, improved bioavailability and solubility of poorly soluble drugs, and the ability to target specific organs [10].

APPLICATIONS OF NANOTECHNOLOGY IN TARGETED DRUG DELIVERY

Dendrimers, as a newly emerged class of nanocarrier, were fabricated by a controlled method of sequential growth by which highly branched, monodispersed macromolecular structures can be formed. The highly branched structure leads to a large number of terminal functional groups, which can allow for multiple modifications and flexible design. This nanoparticle class also has highly controlled molecular weights that affect particle clearance and toxicity. There are different kinds of dendrimers that were reported for cytotoxicity and cellular uptake investigation at different sizes and terminal modifications. Various physical enhancement approaches, such as elevated temperature, ultrasound exposure, and osmotic pressure opening, were employed to facilitate dendrimer-based drug delivery. Moreover, attempts were made to decrease the toxicity of dendrimers by chemical modifications, including carboxylation, PEGylation, and acetylation. Figure 4 demonstrates the strategies to improve the performance of dendrimer-based drug carriers. All these efforts aim to obey the "sweet spot" principle of drug delivery, where the best efficiency and least adverse effects can be achieved [11, 12]. Advances in drug-delivery nanocarriers have improved and expanded the ability to efficiently deliver drugs for disease treatment. A variety of synthetic nanoparticles were created using different base materials (e.g., lipids and metals) and using techniques involving polymeric nanoparticles, liposomal nanoparticles, micellar nanoparticles, and dendritic polymers. These nanoparticles have been employed in significant disease treatment studies, especially in targeting unmanageable diseases such as cancers and viral infection. Because the design of the nanocarriers can control multiple parameters, including size, shape, and surface modification, many desirable functions can be achieved. Individually or in combination, these functions

would redesign drug delivery by facilitating the recognition of disease sites by the drug carriers, improving the cellular uptake of the drug carriers, enabling a controlled release of drugs inside the target cells, bioavailability of poorly soluble drugs, and decreasing the drug toxicity and side effects [13].

CHALLENGES AND FUTURE DIRECTIONS

Currently, there are notable concerns regarding nanocarrier systems, such as hindered cellular penetration due to undesirable charge, vast surface area promoting non-specific uptake, lack of effective localization, and systemic side effects. Designing more refined industrial equipment and optimizing the production process are crucial to addressing these current challenges. Furthermore, the emergence of novel exploration tools and technologies, such as advanced analytical instruments comprised of in situ and operando systems, would be beneficial to the evaluation of drug delivery systems and for drug manufacture [14, 15]. Concurrently, the continuous advancement in biomedicine and nanotechnology has significantly contributed to the research of nanotechnology and drug delivery systems, offering valuable insights. Nanoscale drug delivery systems (NDDS), as novel vehicles fabricated in the nanometer scale, have been successfully applied in delivering poorly soluble drugs, including several successful nanocarriers commercialized, such as Abraxane, Doxil, and Marqibo. In addition, numerous ongoing clinical trials are expected to promote the advancement of novel nanotherapeutics, whereas the recent promotion of the Nanomedicine Initiative will facilitate thousands of nanotherapeutics to be put into market, ultimately highlighting future directions for improvement in this field [16].

CONCLUSION

The advancements in nanotechnology have significantly impacted the development of drug delivery systems, offering promising solutions to enhance therapeutic efficacy, reduce toxicity, and achieve targeted drug delivery. The introduction of nanocarriers such as liposomes, dendrimers, and polymeric nanoparticles has opened new avenues for treating complex diseases, particularly in oncology. However, challenges such as non-specific uptake, systemic side effects, and difficulties in manufacturing scalability continue to hinder widespread clinical adoption. Future research should focus on refining nanocarrier designs, improving targeting efficiency, and developing scalable production techniques. As these challenges are addressed, nanotechnology is poised to play a pivotal role in the future of medicine, particularly in the realm of personalized therapies and precision drug delivery.

REFERENCES

1. Nguyen TT, Nguyen TT, Vo TK, Nguyen MK, Van Vo T, Van Vo G. Nanotechnology-based drug delivery for central nervous system disorders. Biomedicine & Pharmacotherapy. 2021 Nov 1; 143:112117. sciencedirect.com
2. Oroojalian F, Charbgoo F, Hashemi M, Amani A, Yazdian-Robati R, Mokhtarzadeh A, Ramezani M, Hamblin MR. Recent advances in nanotechnology-based drug delivery systems for the kidney. Journal of controlled release. 2020 May 10; 321:442-62. [HTML]
3. Sohail M, Sun Z, Li Y, Gu X, Xu H. Research progress in strategies to improve the efficacy and safety of doxorubicin for cancer chemotherapy. Expert review of anticancer therapy. 2021 Dec 2;21(12):1385-98. [HTML]
4. Anik MI, Hossain MK, Hossain I, Mahfuz AM, Rahman MT, Ahmed I. Recent progress of magnetic nanoparticles in biomedical applications: A review. Nano Select. 2021 Jun;2(6):1146-86. wiley.com
5. Haleem A, Javaid M, Singh RP, Rab S et al. Applications of nanotechnology in medical field: a brief review. Global Health Journal. 2023. sciencedirect.com
6. Nikezić AV, Bondžić AM, Vasić VM. Drug delivery systems based on nanoparticles and related nanostructures. European Journal of Pharmaceutical Sciences. 2020 Aug 1; 151:105412. [HTML]
7. Rommasi F, Esfandiari N. Liposomal nanomedicine: applications for drug delivery in cancer therapy. Nanoscale Research Letters. 2021. springer.com
8. Mojarad-Jabali S, Farshbaf M, Walker PR, Hemmati S, Fatahi Y, Zakeri-Milani P, Sarfraz M, Valizadeh H. An update on actively targeted liposomes in advanced drug delivery to glioma. International Journal of Pharmaceutics. 2021 Jun 1; 602:120645. [HTML]
9. Rastogi V, Yadav P, Porwal M, Sur S, Verma A. Dendrimer as nanocarrier for drug delivery and drug targeting therapeutics: a fundamental to advanced systematic review. International Journal of Polymeric Materials and Polymeric Biomaterials. 2024 Mar 3;73(4):310-32. [HTML]

10. Zielińska A, Carreiró F, Oliveira AM, Neves A, Pires B, Venkatesh DN, Durazzo A, Lucarini M, Eder P, Silva AM, Santini A. Polymeric nanoparticles: production, characterization, toxicology and ecotoxicology. Molecules. 2020 Aug 15;25(16):3731. mdpi.com
11. Chis AA, Dobrea C, Morgovan C, Arseniu AM, Rus LL, Butuca A, Juncan AM, Totan M, Vonica-Tincu AL, Cormos G, Muntean AC. Applications and limitations of dendrimers in biomedicine. Molecules. 2020 Sep 1;25(17):3982. mdpi.com
12. Mittal P, Saharan A, Verma R, Altalbawy FM, Alfaidi MA, Batiha GE, Akter W, Gautam RK, Uddin MS, Rahman MS. Dendrimers: a new race of pharmaceutical nanocarriers. BioMed Research International. 2021;2021(1):8844030. wiley.com
13. Sultana A, Zare M, Thomas V, Kumar TS, Ramakrishna S. Nano-based drug delivery systems: Conventional drug delivery routes, recent developments and future prospects. Medicine in Drug Discovery. 2022 Sep 1; 15:100134. sciencedirect.com
14. Hafeez MN, Celia C, Petrikaite V. Challenges towards targeted drug delivery in cancer nanomedicines. Processes. 2021. mdpi.com
15. Tiwari N, Osorio-Blanco ER, Sonzogni A, Esporrín-Ubieto D, Wang H, Calderón M. Nanocarriers for skin applications: where do we stand? Angewandte Chemie International Edition. 2022 Jan 17;61(3): e202107960. wiley.com
16. Herdiana Y, Wathoni N, Shamsuddin S, Muchtaridi M. Scale-up polymeric-based nanoparticles drug delivery systems: Development and challenges. OpenNano. 2022. sciencedirect.com

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