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Targeted Drug Delivery Systems: Current Trends and Future Prospects

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Abstract

The majority of dosage forms available today have subpar biopharmaceutical and pharmacokinetic qualities. In order to prevent harm to other tissues or organs, a suitable "drug delivery system" that delivers the active drug molecule only to the site of action has to be created. A technique for giving medications to patients at the intended location or site of action is called targeted drug delivery. Targeted drug delivery is one of the most innovative approaches to sickness diagnosis and treatment in the medical sciences. Review the many studies on current developments and potential future directions in targeted drugs delivery systems in this article. The review found that TDD improves treatment effectiveness by reducing side effects and dose requires. To improve medication transport and release, a variety of carriers have been investigated, including as nanoparticles, liposomes, micelles, and biodegradable polymers. Effectively targeting many tumour locations is still a difficulty in cancer therapy, despite attempts to create highly selective delivery methods. It is expected that as TDD systems develop, they will play a bigger part in treating complicated illnesses including cancer, neurological problems, and autoimmune issues, opening up new possibilities in precision medicine.

Keywords: Targeted drug delivery systems (TDD), Diagnosis and treatment of diseases, Nanomaterial-based drug delivery systems (NBDDS), Active and passive targeting, Conventional drug delivery systems (DDS), Nanocarriers, etc.

1 Introduction

The body uses drug delivery systems (DDS) to distribute therapeutic medications as required to safely provide the intended therapeutic effect. These systems are often created to lower adverse effects, boost

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pharmacological effectiveness, and enhance the active compounds' water solubility and chemical stability [1], [2]. The first sustained release version of Dexedrine was produced in the 1950s, and since then, modern drug delivery technologies have continuously advanced. Targeting the biological location with therapeutic medication concentrations and maintaining them is the aim of every drug delivery method. In recent years, nanoparticles have shown significant promise as carriers in current medication delivery methods [3], [4]. Encapsulating medications in nanoparticles, such as liposomes, dendrimers, nanocapsules, nanospheres, and micelles, among others, increases the therapeutic index and lowers the negative side effects [5].

A. Targeted Drug Delivery

A medicine may be delivered to a particular organ, tissue, cell, or receptor using a technique called targeted drug delivery (TDD). By lowering cytotoxicity to healthy cells and increasing the medication's bioavailability and effectiveness, this lowers the dose necessary in comparison to standard drug delivery [6]. In vitro and in vivo, TDD systems should ideally be chemically and physically stable, non-immunogenic, and biochemically inert (non-toxic). In addition to having uniform capillary distribution, they must to have restricted drug distribution to specific cells, tissues, or organs [7]. The pharmacological action of TDD should not be dependent on the release kinetics, and the rate of drug release should be predictable and controlled [8]. It should deliver a therapeutic dose of medication with little to no leaking while in transportation. Utilising carriers that are biodegradable or easily removed from the body is recommended. It should be straightforward or very simple to prepare the distribution system, reproducible, and economical [9][10].

B. Strategies for drug targeting

Drug targeting may be approached in several ways, some of which include [11]:

Passive targeting: Passive targeting is the term used to describe drug delivery techniques that seek to distribute the medication into the systemic circulation. The body responds to the medication's physicochemical characteristics or the drug delivery system's ability to trap the drug until it reaches the target spot by passively targeting it.

Active targeting: With this approach, the medication is targeted once the target group has been identified and affixed to the drug delivery system's surface by the target cells' receptors. Albumin protein, bioadhesive nonionic surfactants, and antibodies are examples of the target group. There are three categories of active targeting: intracellular targeting, cell targeting, and first-order targeting, which is also known as organ targeting.

Inverse targeting: Its objective is to stop the medication delivery technique from being passively absorbed by the reticulum-endothelial system (RES). Large molecules of dextran sulphate or a large quantity of the blank drug delivery system may be injected to block the normal uptake function of RES, resulting in a saturation of RES and the suppression of the defence mechanism. For medication targeting to non-RES organs, inverse targeting is particularly helpful.

Ligand mediated targeting: Both synthetic micro-emulsions of low-density lipoprotein (LDL) particles coated with Apo proteins and natural LDL particle receptor uptake are necessary for this kind of medication targeting.

Physical targeting: In order to target medication delivery systems to a specific place, the physical targeting approach aims to modify them externally. Applying an electric field, altering the pH, and changing the temperature are examples of the physical alterations. This approach has great promise for targeting genes and tumours.

Dual targeting: Through a drug delivery system, the dual targeting mechanism increases the therapeutic efficacy by allowing the carrier to work in concert with the entrapped medication. An antiviral drug placed onto a carrier molecule with antiviral action, for example, increases the therapeutic effect.

C. Applications of targeted drug delivery system

- Treatment of cancerous tumours is the most important use of targeted drug delivery, while it is often employed to treat a variety of diseases, including vascuar disorders, polygenic diseases, etc.
- Drugs may be delivered using liposomes to treat illnesses like TB. TB is traditionally treated using skin-to-chemotherapy, which is not very successful. This might be because the chemotherapy does not reach a high enough concentration at the infection site. Better concentration building at the infection site and improved microphage penetration are made possible by the liposome delivery mechanism [12].

2 Literature Review

(Alshammari et al., 2024) [13] provides a thorough grasp of the architecture and physiological environment of the colon while examining the development and efficacy of colon-targeted medication delivery systems. The evaluation offers information about the benefits and possible drawbacks of each application. The research highlights how crucial it is to conduct regulated in vitro drug testing throughout the development stage. The future directions for effective growth in this discipline are also covered. For researchers navigating the ever-changing area of colonic drug administration, this review is an invaluable resource since it integrates information from anatomy, formulation procedures, and evaluation approaches.

(Tiwari et al., 2023) [14] Either passive or aggressive methods are used to direct the medication to the tumour location. Active targeting uses ligand-coated nanoparticles, while passive targeting uses the tumour microenvironment and improved permeability and retention effect. Nanotechnology is being used to detect cancer early on by identifying cancer-specific biomarkers using tumour imaging. Examples of the use of nanotechnology in cancer therapy include the development of "photoinduced nanosensitizers, the reversal of multidrug resistance, and the efficient transport" of RNA molecules and CRISPR/Cas9 for therapeutic reasons. Nevertheless, more research is required in the area of creating and using nanoparticles for better cancer detection, even with the current developments in nano-oncology.

(Cheng et al., 2023) [15] "Nanomaterial-based drug delivery systems (NBDDS)", which have unique physicochemical and biological properties, are often used to improve the safety and therapeutic efficacy of encapsulated drugs. By integrating "therapeutic drugs with nanoparticles" via logical targeting pathways, nano-targeted delivery systems were created to get around the main drawbacks of conventional drug treatment, including poor stability and solubility, a lack of transmembrane transport, a brief circulation time, and undesirable toxic effects. Here, we examined the latest advancements in therapeutic treatments using a variety of nanomaterial-based systems and targeted design methodologies. The difficulties and viewpoints of smart systems in accurately addressing various intravascular and extravascular disorders were also covered.

(Mumtaz et al., 2023) [16] Drugs for the treatment of acute disorders may now be transported in novel ways thanks to nanotechnology, which has made this work easier to do. However, by using nanoparticles as efficient medication transporters, it has been resolved. The main topics of this research are the types and properties of nanomaterials (NMs) used, the drawbacks of conventional "drug delivery systems (DDS)", and the common ways that drugs are administered via the skin. We have listed the most recent advancements in NMs for drug delivery and their mode of action, such as "carbon-based NMs, inorganic/metal-based NMs, polymeric NMs, and hybrid NMs". The present obstacles and difficulties that hinder the transition of nanomaterials from study to practice are also addressed in this paper, along with recommendations for more efficient use of nanomaterials in a variety of diseases.

(J. Li et al., 2023) [17] Significant oncotherapy discoveries and advancements have been made by several experts in this discipline. Additionally, examine new technology and tailored medication delivery approaches to improve oncotherapy. We also go over two common medication delivery methods based on different nanocarriers for improving tumour therapy: passive and active targeting. The comparison and fusion of active and passive targeting are also conducted in the meanwhile. The related difficulties of targeted drug delivery methods, both active and passive, are also covered, along with the opportunities for future research.

(Prabahar et al., 2021) [11] The purpose of the targeted drug delivery system in the use of chemotherapeutic medications to treat cancer is to guarantee that the pharmacological activity of the therapeutic agent only affects the diseased organs and does not damage the healthy ones. Medication targeting may be achieved by using various carriers that preserve and deliver the complete medication to a predetermined organ or tissue. A variety of carrier types, including "dendrimers, noisomes, ufasomes, virosomes, cubosomes, nanobots, transferosomes, nanotubes, nanowires, nanoshells, quantum dots, nanopores, gold nanoparticles", and more, may be used for drug targeting. There are several therapeutic targeting strategies, including as "ligand-mediated targeting, physical targeting, inverse targeting, double targeting, dual targeting, active targeting, and passive targeting". A realistic way to deliver a therapeutic chemical to a specific place without putting other organs at risk is drug targeting.

(Dunuweera et al., 2018) [9] A complex method of giving patients their prescriptions in a manner that increases the concentration of the drug only in the targeted organs, tissues, or cells is called targeted drug delivery, or TDD. TDD delivers a least necessary therapeutic agent to a sick body location for a long

duration. This prevents drugs from harming healthy tissue by controlling the amounts of drugs in plasma and tissue. "Neutrophils, fibroblasts, artificial cells, lipoproteins, liposomes, inorganic nanoparticles, magnetic nanoparticles, soluble polymers, biodegradable microsphere polymers (natural and synthetic), and immunological micelles" are examples of drug carriers found in advanced delivery systems. When selecting a vehicle, one should take into account side effects or cytotoxicity to healthy cells, the chemical and physical characteristics of pharmaceuticals, the drug delivery route, the intended site, and disease. Thus, TDD formulations take into account target cell features, indicators or transport carriers that deliver drugs to receptors, ligands, and physically regulated components.

(Kumar et al., 2017) [18] Delivering medications to patients at the intended location or site of action is known as targeted drug delivery. By lessening the negative effects of the medication, this increases therapy effectiveness. This method's intrinsic benefit results in the necessary medication being administered at a lower dosage with fewer adverse effects. Lipoproteins, liposomes, and microspheres are among the several drug carriers that may be used in this advanced delivery method. The current review addresses the research update on targeted drug delivery systems, as well as its benefits, drawbacks, and need.

(Thakur et al., 2015) [19] The latest developments in drug delivery systems mostly centre on intelligent drug delivery systems, which address the safe and effective distribution of drugs at the appropriate time and dosage. A smart drug delivery system includes the use of hydrogels, nanoparticles, and microencapsulation methods. Drugs ranging from painkillers to chemotherapy may be delivered using nanoparticles, which can be inserted into the skin, brain, or spinal cord. Because of their connection to self-regulation and controlled time drug monitoring systems, these new developments in drug delivery systems have therefore shown to be methods for improving health in the future.

3 Conclusion

A cutting-edge method in medical research for accurate illness detection and therapy is targeted drug delivery, or TDD. By ensuring drug molecules reach specific sites within the body, TDD minimizes dosage requirements and reduces side effects, enhancing therapeutic efficacy. Various carriers, including nanoparticles, liposomes, micelles, and biodegradable polymers, have been explored to optimize drug transport and release. The advent of advanced technologies such as 3D printing has further enabled personalized medicine by controlling drug release kinetics. In cancer treatment, despite efforts to develop highly selective delivery mechanisms, challenges remain in effectively targeting multiple tumor sites. Nanocomposites and nanoarchitectures offer promising solutions, enabling controlled drug interactions at targeted locations. Moreover, biodegradable nanomaterials facilitate sustained and localized drug release, improving treatment outcomes. The continuous advancements in TDD systems, including dual-drug delivery and bioengineered carriers, present new opportunities for enhanced therapeutic strategies. Future research should focus on refining drug targeting precision, minimizing off-target effects, and exploring novel biomaterials to improve drug stability and efficacy. As TDD systems evolve, their role

in treating complex diseases such as cancer, neurological disorders, and autoimmune conditions is expected to expand, offering a new frontier in precision medicine.

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