Review Article

Advancements in Targeted Drug Delivery Systems

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ABSTRACT

Targeted drug delivery systems (TDDS) have revolutionized the field of pharmaceuticals by providing a precise and efficient way to deliver medications to specific sites of action. This approach reduces adverse effects, enhances therapeutic efficacy, and improves patient compliance. TDDS utilizes carriers such as liposomes, nanoparticles, and microspheres to deliver drugs to targeted tissues or cells. Active and passive targeting strategies enable the delivery of therapeutic agents to specific sites, increasing treatment outcomes. This review highlights the types, advantages, and applications of TDDS in various diseases, including cancer, breast cancer, heart disease, infectious diseases, and chronic diseases. Recent advancements in nanotechnology, precision medicine, and innovative delivery mechanisms are also discussed. The benefits of TDDS include increased efficacy, decreased toxicity, and improved patient outcomes. However, challenges such as resistance, limited availability, regulatory barriers, and high costs need to be addressed. Future perspectives include integrating TDDS with emerging technologies like artificial intelligence and machine learning to create more effective and personalized drug delivery systems. Overall, TDDS holds great promise for improving treatment outcomes and patient quality of life.

Keywords: Targeted drug delivery systems, Nanoparticles, Liposomes, Cancer treatment, Personalized medicine.

1. INTRODUCTION

By administering medications straight to the site of action or absorption, targeted drug delivery systems (TDDS) reduce adverse effects and boost therapeutic efficacy. To decrease toxicity and increase patient compliance [1]. TDDS seeks to make the appropriate amount of medications available at the intended site of action [2]. The significance of TDDS resides in its capacity to get around the drawbacks of traditional drug delivery methods. The constraints include non-specific toxicity, lack of pharmacological selectivity towards a harmed site, and unequal biodistribution of pharmaceutical research [3].

One of the most promising strategies to cure a number of diseases such as cancer, coronary artery disease and neurological disorders is targeted drug delivery. The strategy depends on using delivery systems that can deliver drugs to target specific tissue or cells with higher clarity, reducing damage to healthy tissues and increasing therapy effectiveness[4]. Recent advances in targeted drug administration, including liposomes applications, nanoparticles and other new approaches of deliveries are introduced in this review [5].

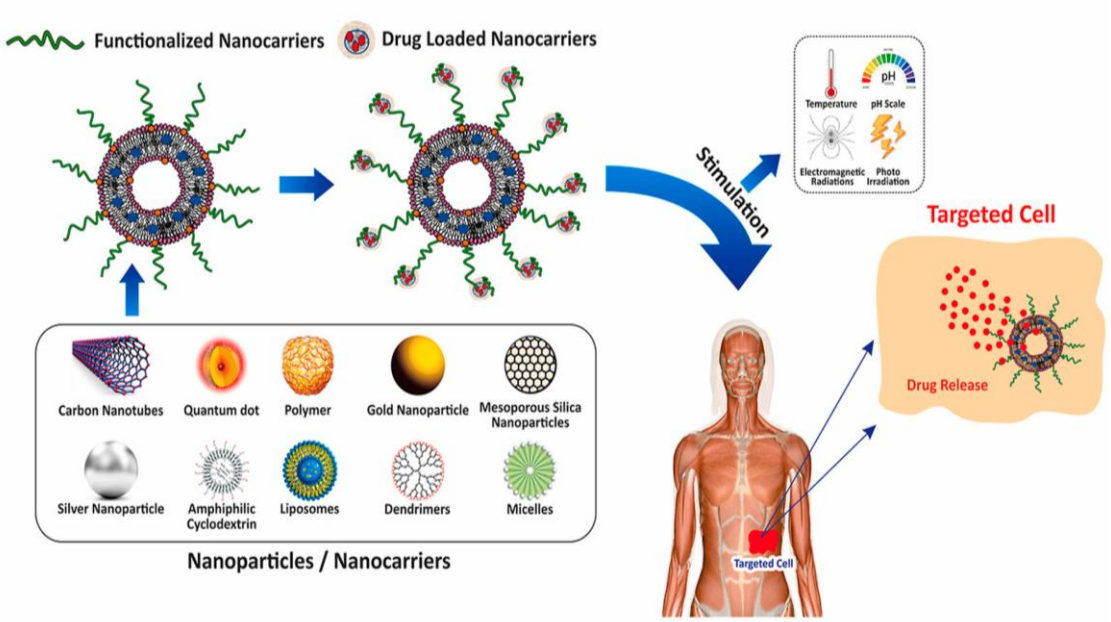

Figure 1: Different nanoparticles reaching targeted sites in body [6,7,8]

2. TYPES OF TARGETED DRUG DELIVERY SYSTEM:

2.1 Active Targeting

Using carriers or matrices that are precisely made to target cells or tissues is known as active targeting. These carriers are frequently combined with targeting ligands that identify and link to specific binding sites or antigens on the target cells, such as aptamers, peptides, or antibodies [9].

When compared to non-targeted versions, active targeting results in larger local intravascular concentrations of nanoparticles and longer retention times in tumor tissues that do not leak [10].

2.2 Passive Targeting:

Conversely, passive targeting relies on the drug carrier's organic dispersion and buildup among the target tissue.

There are numerous ways to accomplish this, including:

- **Enhanced permeability and retention (EPR) effect:** The target tissue's inadequate lymphatic drainage and leaky vasculature cause the drug carrier to accumulate there[11].
- **Size-dependent targeting**: The drug carrier is made to accumulate within three, depending on the size and properties of the target tissue[3].

Examples of Passive Targeting including:

- **Liposomes:** Lipid-based organelles that can build up in target tissues as a result of the EPR effect.
- **Nanoparticles:** Depending on their size and qualities, these tiny particles can accumulate in target tissues [9].

3. CARRIERS FOR TARGETED DRUG DELIVERY:

3.1 LIPOSOMES:

The distinct properties, benefits, and uses of liposomes, a form of nanocarrier, have led to their widespread use in targeted drug delivery systems [4].

Characteristics:

1) **Phospholipid bilayer structure:** The hydrophilic core of liposomes is encased in a phospholipid bilayer.
2) **Size and shape:** Liposomes can be generated in many kinds of shapes, such as spherical, oval, and tubular, and range in size from 50 to 500 nm [3,10].
3) **Surface charge:** The charge on the outside of liposomes can be either positive, negative, or neutral.
4) **Targeting ligands:** To target certain cells or tissues, liposomes can be connected to targeting ligands including aptamers, peptides, or antibodies [11].

Advantages:

1) **Biocompatibility:** Liposomes that are non-toxic and biocompatible due to their intrinsic phospholipid composition.
2) **Targeted delivery:** By directing liposomes to particular cells or tissues, systemic adverse consequences can be controlled.
3) **Regulated release:** Liposome formulations allow for the managed release of their payload [6].
4) **Improve solubility:** Drugs that are hydrophobic can be dissolved by liposomes, increasing their bioavailability[12].

Applications:

1) **Cancer therapy:** Chemotherapy medication such doxorubicin and paclitaxel have been supplied to tumor cells via liposomes.
2) **Gene treatment:** For gene therapy applications, liposomes have been utilized for transferring genetic material, including DNA and siRNA, to cells [13].
3) **Vaccination delivery:** Adjuvants and vaccination antigens have been delivered to immune cells through liposomes.
4) **Treatment of infectious diseases:** Antibiotics and antifungals have been administered to cells with disease via liposomes [14].

Types of Liposomes:

1) **Traditional liposomes:** These are carried out out of a single phospholipid bilayer.
2) **Long-circulating liposomes:** Made up of a phospholipid bilayer using additional polymers, like PEG, that improve the duration of circulation.
3) **Cationic liposomes:** To aid in gene shipment, cationic lipids are added to a phospholipid bilayer [15].
4) **Targeted liposomes:** To target particular organs or cells, they consist of a phospholipid bilayer that has been combined with targeting ligands [9].

3.2 NANOPARTICLE:

Nanoparticles are described as "particles with dimensions in the range of 1-100 nanometers, which exhibit unique physical and chemical properties that differ from those of bulk materials" through the National Nanotechnology Initiative. They are made of various materials like metals, ceramics, polymers and lipids [16].

Characteristics:

1) **Size:** The typical diameter of a nanoparticle is 1–100 nm.
2) **Shape:** Nanoparticles might be an irregularly shaped, spherical, or rod-shaped [17].
3) **Composition:** Metals, ceramics, polymers, inorganic clay and lipids are just a few of the components that can be utilised to create nanoparticles.

4) **Surface features:** Nanoparticles can have various surface attributes, such as charge, hydrophobicity, and aiming ligands [18].

Types of Nanoparticles:

1) **Lipid-based nanoparticles:** Made up of a phospholipid bilayer on outermost layer of a lipid core.
2) **Polymeric nanoparticles:** Firstly composed of biodegradable components, those tiny molecules made up of a polymeric core [6,19].
3) **Metallic nanoparticles:** Usually composed of iron oxide, silver or gold, these particles have a metal core.
4) **Ceramic nanoparticles:** Usually composed of alumina or silica, these particles possess a ceramic core.
5) **Quantum dots:** Fluorescent, tiny semiconductor particles [20].

Advantages:

1) **Targeted delivery:** NPs can be developed to specifically target tissues or cells.
2) **Controlled release:** NPs have the capability of releasing their payload in a controlled manner.
3) **Greater solubility:** Hydrophobic medications can be dissolved by NPs, increasing their bioavailability [21].
4) **Reduced toxicity:** By minimizing exposure to healthy tissues, NPs can lessen systemic toxicity.

Applications:

1) **Cancer therapy:** NPs have been utilized to deliver chemotherapeutic drugs, such as doxorubicin and paclitaxel [22].
2) **Gene therapy:** DNA and siRNA are examples of genetic material that has been transmitted by NPs.
3) **Treatment of infectious diseases:** Antibiotics and antifungals have been administered using NPs.
4) **Neurological disorders:** curative medicines have been delivered via the blood-brain barrier using NPs [23].

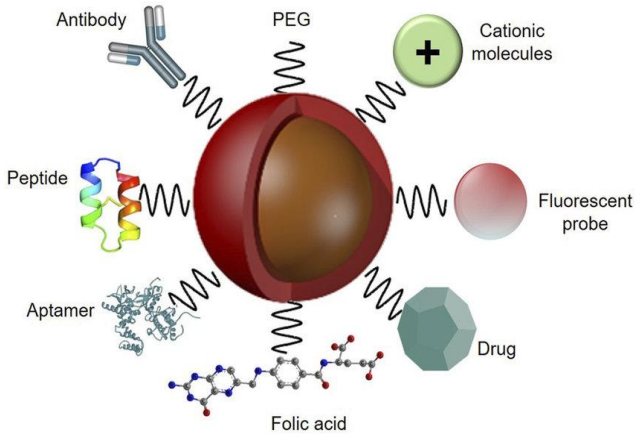

Figure 2: Nanoparticle platform with various targeting ligand [24,25]

3.3 MICROSPHERES:

Small, spherical particles bringing a diameter range of 1-1000 µm, manufactured with various materials, and used for a wide range of applications, including medication administration, tissue engineering, and diagnostics [26].

Characteristics:

1) **Size:** The number of microspheres varies 1-1000 microns.
2) **Shape:** Microspheres have spherical shapes [27].
3) **Material:** microspheres can be made of various materials including polymers, Ceramics and metals.
4) **Surface properties:** Microspheres have various superficial properties such as loads Hydrophobicity and ligand targets [26].

Advantages:

1) **Targeted delivery:** Microspheres may prove targeted to specific cells or tissues, reducing systemic side effects.
2) **Controlled release:** Microspheres can release their payload in a controlled manner, minimizing toxicity and boosting efficacy.
3) **Improved bioavailability:** Microspheres can improve the bioavailability of drugs, which involves proteins and peptides [14].
4) **Biocompatibility:** Microspheres can be made of biocompatible materials, reducing the risk of unfavorable conditions.

Applications:

1) **Drug delivery:** Microspheres can deliver peptides, proteins, and small molecules.
2) **Tissue engineering:** For tissue engineering applications, microspheres can serve as scaffolds [21].
3) **Diagnostics:** For methods of imaging like MRIs and CT scans, microspheres can be deployed as contrast agents.
4) **Cosmetics:** Microspheres are small and can be utilized in skincare and haircare products, among other cosmetics [6,28].

4. TARGETED DRUG DELIVERY SYSTEMS FOR SPECIFIC DISEASES:

4.1 CANCER:

With its increased efficacy, decreased toxicity, and improved patient outcomes, targeted drug delivery systems (TDDS) have grown into a potential cancer treatment strategy [7,29].

Steps involved in TDDS for Cancer Treatment:

1) **Target identification:** Locating going molecular targets, notably receptors or antigens, on cancer cells.

2) **Targeting ligand design:** Producing antibodies or peptides that show specific affinity to the intended targets.

3) **TDDS formulation:** producing TDDS with the specific ligands, like liposomes or nanoparticles 30, and the therapeutic medications[30].

4) **Administration:** Allowing the patient the TDDS, either locally or systemically.

5) **Targeting and uptake:** Through receptor-mediated endocytosis, the TDDS targets and gets taken in by the cancer cells [6,28].

6) **Release of therapeutic agents:** The anti-cancer effects of the therapeutic chemicals get released from the TDDS either via diffusion or degradation [31].

Mechanisms of TDDS in Cancer Treatment:

1) **Induction of apoptosis:** Medications which induce cancer cells to undergo apoptosis, or programmed cell death, can be administered through TDDS.

2) **Inhibition of cell proliferation:** Therapeutic medicines that prevent cell growth and proliferation can be delivered using TDDS [25,32].

3) **Inhibition of angiogenesis:** TDDS can administer therapeutic drugs that prevent the production of new blood vessels, depriving the tumor of oxygen and nutrition.

4) **Immunomodulation:** By delivering therapeutic chemicals that alter the immune system, TDDS could enhance immune responses fighting tumors [33].

Benefits of TDDS for Cancer Treatment:

1) **Increased Efficacy:** By transporting therapeutic drugs immediately to cancer cells, TDDS can enhance treatment results and lower systemic toxicity.

2) **Decreased Toxicity:** By minimizing exposure to healthy tissues, TDDS can lower the chance of detrimental impacts and enhance the quality of life for patients.

3) **Improved Patient Outcomes:** TDDS can increase patient survival rates and lower the chance of cancer recurrence via enhanced treatment outcomes [34].

4.2 BREAST CANCER (BC):

Breast cancer is the most commonly occurring cancer in women and represents the leading cause of death associated with cancer among females globally. Like most cancers, BC is a heterogeneous disease with different molecular subtypes [30]. The major subclasses identified by genetic profiling are: Basal-like, Luminal-A, Luminal-B, human epidermal growth factor 2 (HER2)-positive/HER2-enriched/HER2-overexpressing BC, and normal-like tumors [35].

Most chemotherapeutic drugs have a short half-life and a high clearance rate in the bloodstream. Nowadays, low-molecular-weight substances that diffuse rapidly into healthy tissues and distribute uniformly throughout the body make up the great majority of clinically utilized medications [37].

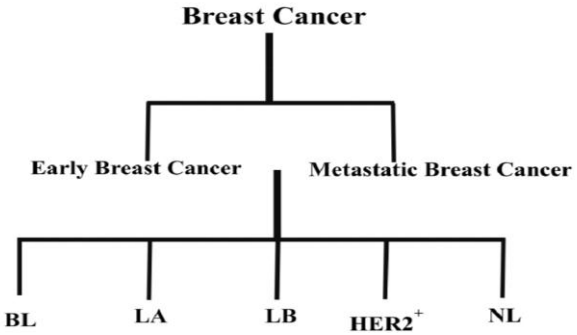

Figure 3: Classification of Breast Cancer [36]

The target site receives only small amounts of the drugs, such as doxorubicin (DOX), giving them a narrow therapeutic index with a sensitive balance between efficacy and toxicity. CUR (1,7-bis (4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione) is a naturally occurring polyphenol that is obtained from the ginger family member turmeric [38]. The therapeutic effects of CUR on the nervous, respiratory, cardiovascular, urinary, reproductive, digestive and hepatobiliary, musculoskeletal and endocrine systems, as well as the skin, have been confirmed by previous studies. CUR has also been shown to be a potent anti-inflammatory, antitumor, and antioxidant agent [39]. Based on the immunohistochemical expression of estrogen receptor (ER), progesterone receptor (PR), and human epidermal growth factor receptor 2 (HER2), BC can be classified into four major subtypes: hormone receptor (HR)+/HER2+, HR+/HER2−, HR−/HER2+ and HR-/HER2 [33].

4.3 HEART DISEASE:

A potential cure for heart disease is the intravenous administration of cardioprotective medications to the infarcted coronary and circulatory system. The necessity for superior therapies caused a boost in the administration of targeted delivery of medicines to the heart [28]. As the highest cause of premature death over all diseases, cardiovascular-related diseases snatched the lives of about 18 million people in, resulting in 32% of all casualties worldwide, according to the World Health Organization (WHO). An important area of concern among CVD is myocardial infarction (MI) brought on by coronary heart disease (CHD), that is responsible for more than 75% of sudden cardiac arrest (SCD) [40]. They have successfully demonstrated that they may transport a variety of biomaterials, including imaging agents, peptides, proteins, nucleic acids, and low molecular weight pharmaceuticals, to the target tissue [36]. Micelles are promising containers for the delivery of therapies used to regulate infarct healing during the long-term stage of MI as well as cardioprotective medications required for the acute stage of MI. Since suited drug delivery systems offer advantages to increase efficacy and decrease off-target effects, their proper application is always essential [41]. The most prevalent way of delivering therapeutic elements to the targeted tissue are

nanoparticles (NPs). The lipids, polymer chains, dendrimers which carbon dioxide nanotubes, and copper nanoparticles are a few examples of the nanomaterials and structures that can be linked to make NPs for the delivery of medicinal drugs [42]. A phytoestrogen and isoflavone based on soy, genistein (Gen) has considerable antiangiogenic effects by inhibiting the transcription of pro-angiogenic factors such as Vascular Endothelial Growth Factor (VEGF) [40].

4.4 INFECTIOUS DISEASES:

Targeted Drug Delivery Systems (TDDS) minimize exposure to healthy tissues while delivering therapeutic drugs directly to the site of infection in infectious disorders [31].

Steps Involved:

1) **Target Identification:** Assess the precise molecular targets of infections, including viruses, fungi, as well as bacteria.
2) **Targeting Ligand Design:** Make targeting ligands, such as peptides or antibodies, that bind to the designated targets precisely [43].
3) **TDDS formulation:** Design TDDS with the targeted ligands, like liposomes or nanoparticles, and the therapeutic medications.
4) **Administration:** Treat the patient the TDDS locally or systemically.
5) **Targeting and Uptake:** By means of receptor-mediated endocytosis, the TDDS recognizes the pathogens and is absorbed by them.
6) **Release of Therapeutic compounds:** Either by diffusion or degradation, the therapeutic compounds leave the TDDS and start to work as antimicrobials [44].

Mechanisms:

1) **Regulation of Pathogen development:** Therapeutic medicines that prevent pathogen expansion and replication can be delivered using TDDS.
2) **Pathogen Killing:** Therapeutic medicines that kill pathogens can be delivered by TDDS, either directly by cytotoxicity or by stimulating host immunological responses [45].
3) **Modulation of Host Immune Responses:** Therapeutic medicines that accelerate pathogen clearance by modifying host immune responses can be distributed via TDDS [41].

Benefits:

1) **Increase Efficacy:** By delivering therapeutic chemicals immediately to the infection site, TDDS can enhance treatment results.
2) **Decreased Toxicity:** TDDS can lessen systemic toxicity through regulating exposure to healthy tissues [46].
3) **Better Patient Outcomes:** By lowering the chance of disease progression and promoting patient quality of life, TDDS can enhance treatment results [43].

4.5 CHRONIC DISEASES:

Targeted Drug Delivery Systems (TDDS) decrease exposure to healthy tissues while delivering therapeutic drugs directly to the afflicted tissues or cells to manage chronic disorders[11].

Mechanisms:

1) **Suppression of Disease Progression:** Therapeutic medicines that prevent tissue damage or inflammation, two hallmarks of chronic diseases, can be delivered using TDDS.
2) **Modulation of Cellular Signaling:** Therapeutic medicines that restore normal cellular function by influencing cellular signaling pathways can be delivered using TDDS [47].
3) **Delivery of Regenerative medicines:** To encourage tissue regeneration and repair, TDDS can provide regenerative drugs like growth factors or stem cells [41].

Benefits:

1) **Greater Efficacy:** By delivering therapeutic chemicals straight to the afflicted tissues or cells, TDDS can enhance the curative effects of treatment.
2) **Decreased Toxicity:** TDDS can lessen systemic toxicity by limiting exposure to healthy tissues.
3) **Better Patient Outcomes:** By diminishing the chance of disease progression and elevating patient quality of life, TDDS can enhance treatment results [48].

5. ADVANTAGES OF TARGETED DRUG DELIVERY:

1) **Lowering Drug Resistance**: Focused drug administration can reduce drug resistance by eradicating resistant forms or enhancing therapeutic results by accurately administering pharmaceuticals to the site of the condition [17].
2) **Enhanced Targeting**: By applying expected compounds or antibodies to target distinct cells or tissues, targeted drug administration could improve targeting, diminishing off-target effects along with improving outcomes for therapy [49].
3) **Reduce Systemic Exposure**: By delivering treatments direct to the disease site, lessening the quantity of prescription that enters the bloodstream, and minimizing negative effects, specific drug administration may lower systemic exposure [31].
4) **Improved Efficacy:** By delivering medication right to the disease's site, targeted administration of drugs may boost therapeutic effectiveness by minimizing requirements for dosage and growing patient outcomes [34].

5) **Decreased Toxicity:** Targeted drug delivery may lessen the negative impacts of treatment by reducing side effects, improving patient quality of life, and limiting the amount of time that healthy cells are exposed to the drug.

6) **More Patient Compliance:** By reducing both the amount and duration of treatment, targeted drug delivery might assist patients adhere more strictly to the suggested course of therapy [9].

7) **Increase Bioavailability:** Through improved absorption and slowed metabolism, targeted drug delivery can increase the bioavailability of drugs by delivering them directly to the site of illnesses.

8) **Greater Pharmacokinetics:** Targeted drug administration may improve pharmacokinetics by enhancing drug absorption, distribution, metabolism, and excretion by delivering medications precisely to the epicenter of diseases [50].

6. DISADVANTAGES OF TARGETED DRUG DELIVERY:

1) **Resistance**: Whenever a disease develops antibodies towards drugs, targeted drug delivery can end up in resistance, thereby lowering the effectiveness of the medication [23].

2) **Limiting Availability**: Not every disease or affliction may gain benefit via targeted drug delivery, which limits its scope of use while making it challenging to discover appropriate treatments.

3) **Regulatory Barriers**: Creation and authorization of new targeted medication can be problematic due to regulatory barriers which targeted drug delivery could face [44].

4) **Public Perception**: Patients may be reluctant to accept targeted pharmaceuticals owing to concern about their effectiveness and safety, therefore could present a problem for targeted drug delivery.

5) **High Cost**: While targeted drug administration can be expensive many patients could find themselves not ready to pay for it; this inhibits its widespread use.

6) **Complexity**: Targeted medication delivery might be challenging to put into effect in contexts without limited funds, requiring specialized instruments and expertise [51].

7) **Limited Knowledge:** Developing efficient targeted therapies may prove hard due to the need for enabling an in-depth awareness of the pathophysiology of disease, which is needed for targeted drug delivery [29].

8) **Effects off-Target:** Pharmaceuticals delivered with targeted delivery might exhibit off-target effects, which can limit the use of them and generate side effects by influencing healthy cells or tissues [52].

7. LIMITATIONS OF TARGETED DRUG DELIVERY:

1) **Adaptability:** Targeted drug delivery might be restricted by scalability, where it would prove hard to scale up production of specific treatments, which could hinder their widespread adoption.

2) **Confined Biomarkers are Indicators:** Targeted drug delivery can be hindered by limited biomarkers, when there are only a few biomarkers available to monitor response to therapy and progression of illness [36].

3) **Stability:** The effectiveness and shelf lifespan of targeted medication administration can become compromised if the pharmaceutical or delivery mechanism is unstable.

4) **Immunogenicity:** Having the capacity of the delivery method to induce an immune response may restrict the effectiveness and security of targeted administration of drugs [53].

5) **Toxicity:** The safety and effectiveness of targeted treatment may be restricted whether the drug or delivery technique used is toxic.

6) **Delivery Obstacles:** Drugs might fall short of the desired site because of delivery difficulties such as the blood-brain barrier, a barrier which may prevent targeted delivery of drugs.

7) **Target Heterogeneity:** Since the target site is numerous, it may prevent targeted drug delivery while rendering it harder to generate appropriate targeted therapies [54].

8) **Circumstance Complexity:** Once a condition is complex or multivariate, it could prove problematic to formulate effective targeted therapies, which may hamper targeted drug delivery [35].

8. APPLICATIONS OF TARGETED DRUG DELIVERY:

1) **Vaccine Delivery:** Targeted drug delivery may improve vaccination performance by delivering vaccines directly to the immune system [4].

2) **Wound Healing:** Developmental factors and additional therapeutic agents are often introduced to wounds for targeted administration of medication, which may hurry up the healing procedure. Liposomal compositions can be used for wound dressings to promote the controlled release of wound-healing medicines [55].

3) **Treatment of Ophthalmic Problems**: To prevent the loss of ocular tissues requires targeting within the ocular globe [56]. In ophthalmic preparation, achieving the necessary bioavailability of the medicine is a simple process Niosomes can enhance drug absorption by lowering intraocular pressure 57. Targeted drug administration is an improved method of administering medication to the eye to treat age-related macular degeneration and other visual disorders [58].

4) **Cancer Treatment:** Liposomes containing anticancer drugs can target cancer cells for a long time without damaging healthy cells. Targeted therapy is made possible by liposomes' ability to encapsulate medications and transport them to particular target tissues or cells. This reduces the drug's exposure to healthy tissues, which minimizes adverse effects [59]. The use of nanotechnology has introduced about a new era in the diagnosis, treatment, and management of cancer [60]. Gold nanoparticle sensors have shown the amazing ability to distinguish lung cancer from non-cancerous cell types [61]. Gold nanoparticles are used to detect various kinds of tumor cells, including breast, lung, and prostate cancer [62]. Colorectal, gastric, pancreatic, and hepatic cancers are among the several solid tumors of the gastrointestinal tract that can be treated with nanotechnology [63]. Particularly target cancer cells while protecting healthy cells, natural substances have been intensively considered as potential anticancer treatments [64].

5) **Treatment of Cardiovascular Disease:** Drugs can be distributed to the cardiovascular system employing specific drug administration, therefore reducing the probability of cardiovascular disease and promoting outcomes of therapy [21].

6) **Treatment of Neurological Diseases:** "Neurological disorders" refers a broad category of diseases including the brain, spinal cord, peripheral nerves [65] and Neurological conditions, such as epilepsy, Alzheimer's disease, Parkinson's disease, and multiple sclerosis [66,67]. Nanotechnology's sensitivity, specificity, and precision can assist discover even tiny levels of biomarkers associated with neurological disorders [68]. Drugs can be provided to the brain with targeted drug delivery, which will help eliminate neurological disorders such as Parkinson's and Alzheimer's [69].

7) **Treatment of Infectious Problems:** Antibiotics can be provided locally to the site of infection through targeted delivery of medicines, which improves the management of viral diseases [69]. Liposomes can increase the effectiveness of antibiotics as a drug delivery system. Antibiotics are helpful in the fight against infections because of their ability to stop, target, and regulate their release [70]. Infectious diseases caused by viruses (human immunodeficiency virus (HIV), hepatitis C, and dengue fever), parasites (malaria, trypanosomiasis, and leishmaniasis), and bacteria (tuberculosis and cholera) are major contributions to morbidity and mortality in developing nations. Nanoparticles, including metallic nanoparticles, liposomes, and quantum dots, have been utilized in the diagnosis and therapy of infectious diseases [71].

8) **Gene Therapy:** By delivering genetic material to specific cells or tissues through targeted pharmaceutical administration, hereditary illness can be treated [69].

9) **Personalized Medicine:** Treatment can be personalized based on the needs of all patients utilizing targeted drug delivery.

10) **Treatment of Dermatological Diseases:** Targeted drug delivery techniques that deliver medications to the skin 72 potentially help treat psoriasis and acne[72]. Barriers Nanoccan improve topical treatments for appendage-related skin conditions including alopecia and acne by targeting hair follicles (HF) [73].

9. FUTURE PERSPECTIVES AND CONCLUSION:

The pharmaceutical industry evolves because of new developments in targeted drug delivery systems.

Here are a few significant advancements:

Developments in Nanotechnology medication delivery methods based on nanoparticles: These systems may decrease toxicity while increasing medication solubility, stability, and bioavailability [51]. Nanomaterials for targeted medication delivery, scientists are investigating a range of nanomaterials, including carbon nanotubes, dendrimers, and liposomes.

Methods of Precision Medicine:

Personalized medicine: By considering a person's lifestyle, health information, and genetic profile, TDDS can be developed to meet their personal needs.

Precision targeting: Advanced targeting strategies, such as receptor-mediated targeting and enzyme-mediated targeting, enable drug distribution to specific cells or tissues [74].

Innovative delivery mechanisms:

Transdermal drug delivery systems: Transdermal Drug Delivery System provides significant advantages over oral and injectable methods because of its ability to avoid first pass metabolism and improve patient compliance [75]. TDDS is less invasive and doesn't pain. Patients can give themselves the drug, which makes it easy and cost-effective[76].

Colon-targeted drug delivery systems: To treat diseases including inflammatory bowel disease, researchers are building devices that can administer medications just to the colon [58].

Prospects for the Future:

Integration with developing technologies: TDDS may be combined with state-of-the-art technology like artificial intelligence, machine learning, and the Internet of Things (IoT) to develop more effective and customized medication delivery systems.

Overcoming obstacles: Researchers need to address issues including cost-effectiveness, regulatory frameworks, and scalability in order to ensure the widespread use of TDDS [77].

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