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TARGETED DRUG DELIVERY SYSTEMS IN SURGICAL ONCOLOGY AND CARDIOVASCULAR DISORDERS: EMERGING THERAPEUTIC STRATEGIES

Lasya Marupudi[1*], Ilaf Jabbar al-Taai[2], Francis Pol Costoy Lim[3]

[*1]Department of Pharmacy Practice, Sri Venkateshwara College of Pharmacy; affiliated to Osmania University" Email ID: lasyamarupudi@gmail.com, ORCID ID: 0009-0000-8616-6869
[2]Assistant Lecturer, Department of Pharmacy, Ashur University Email ID: ilaf.jabbar@au.edu.iq, ORCID ID: 0009-0001-6202-1056
[3]American Management University, Utah, USA; Charisma University, Turks and Caicos Islands, ORCID ID: https://orcid.org/0000-0003-1185-5808, Email ID: limfrancispol19@gmail.com

ABSTRACT
Conventional drug delivery systems often suffer from poor specificity, systemic toxicity, and limited therapeutic efficacy. The emergence of targeted drug delivery systems (TDDS), particularly those based on nanotechnology, has provided new opportunities to enhance treatment precision in complex diseases such as cancer and cardiovascular disorders. This review aims to comprehensively analyze the design, mechanisms, and applications of targeted drug delivery systems in surgical oncology and cardiovascular diseases, while highlighting recent advancements, clinical translation, and future directions. A narrative review of recent literature was conducted, focusing on nanotechnology-based delivery platforms, targeting strategies, and emerging therapeutic approaches relevant to oncology and cardiovascular medicine. Advanced drug delivery platforms, including polymeric nanoparticles, liposomes, dendrimers, hydrogels, and nucleic acid-based systems, demonstrated improved drug stability, bioavailability, and site-specific targeting. In oncology, targeted strategies such as ligand-receptor interactions, antibody-mediated delivery, and stimuli-responsive systems enhanced tumor specificity and reduced toxicity. In cardiovascular disorders, nanomedicine enabled targeted treatment of atherosclerosis, myocardial infarction, and inflammation. Emerging technologies, including AI-integrated design, theranostic nanoparticles, and personalized medicine approaches, further improved therapeutic precision. Targeted drug delivery systems represent a promising paradigm shift in modern therapeutics. Despite challenges related to toxicity, scalability, and regulatory approval, continued advancements and interdisciplinary integration are expected to drive their clinical translation and improve patient-specific treatment outcomes.

KEYWORDS: Targeted drug delivery; Nanotechnology; Surgical oncology; Cardiovascular diseases; Theranostics; Precision medicine

1. INTRODUCTION

Drug delivery systems (DDS) have undergone considerable changes in the last few decades, and their composition no longer includes basic formulations, but rather sophisticated platforms that can be used to streamline the therapeutic effects. The classical methods were mainly directed towards systemic administration and this usually resulted in poor distribution of drugs and little efficacy. Nanotechnology has transformed this sector as the development of the nanoscale carriers allowed enhancing drug solubility, stability, and bioavailability (Afzal et al., 2022). Such systems, such as liposomes, polymeric nanoparticles, and micelles, have been shown to accept therapeutic agents and deliver them in a controlled way, thus improving pharmacokinetics (Begines et al., 2020). The clinical translation of nanoparticle-based systems has also been in the limelight of recent advances, and a number of formulations have already made it to the market and shown better indices of therapy (Anselmo & Mitragotri, 2019). The polymeric nanocarriers in particular have become popular because of their versatility and the capacity to deliver a vast array of drugs, such as chemotherapeutic drugs and biologics (Avramovic et al., 2020). Also, new DDS technologies like electrospun fibrous systems have broadened the application of DDS into tissue engineering and localized therapy (Ding et al., 2019). These advances highlight the increasing relevance of the novel drug delivery technologies in the contemporary medicine.

Traditional methods of delivering drugs are still facing many challenges, even with the progressive advancements in the pharmacotherapy. The lack of specificity that leads to systemic toxicity and adverse side effects is one of the main limitations, especially when it comes to cancer treatment (Dadwal et al., 2018). Chemotherapeutic agents, i.e., indiscriminately kill both normal and cancerous cells, resulting in such complications as immunosuppression and organ toxicity. The other significant problem is low adherence to patients because of the need to take medication multiple times a day and the presence of unpleasant side effects, which undermine the effectiveness of treatment (Baryakova et al., 2023). Moreover, traditional preparations often have poor bioavailability and clearance rate out of the organism, which is restrictive to their therapeutic usage (Din et al., 2017). Other biological barriers such as enzyme degradation and recognition by the immunity system also inhibit effective drug delivery. Also, complex disease microenvironments (e.g., tumor heterogeneity or inflammatory vascular conditions) are frequently not treated using traditional therapies. The limitation is especially noticeable when it comes to microbial biofilm and chronic disease treatment, where traditional

drugs have trouble penetrating biomaterials of protection (Dos Santos Ramos et al., 2018). These failures create a need to come up with better advanced delivery systems that can transcend these obstacles.

Targeted drug delivery is proving as a potential approach to the shortcomings of traditional therapeutics as it involves delivery of drugs to disease tissues in particular with minimum off-target effects. Targeted delivery systems allow the oncology to add therapeutic agents to tumor locations to increase its performance and decrease intense toxicity (Chavda et al., 2022). Tumor-specific features that can be utilized by nanocarriers in order to deliver precise targeting include enhanced permeability and retention (EPR) effect, ligand-receptor interactions. The necessity of the special strategies is also important when it comes to cardiovascular diseases, where the local delivery to the affected tissues, including atherosclerotic plaques or the ischemic myocardium, can greatly enhance the treatment response (Chen et al., 2025). Recent developments in nanomedicine have enabled the creation of both viral and non-viral delivery methods that can be used to target genes, proteins, and small molecules to the cardiovascular tissues in direct proportion. In addition, the growing discipline of cardio-oncology underlines the fact that cancer and cardiovascular diseases are interdependent, and a combination of therapies is necessary (Bellinger et al., 2015). Drug delivery systems that are targeted provide a novel chance to overcome such complexities through the provision of precision medicine based on disease-specific pathophysiology and patient variability.

The review is expected to give a general review of targeted drug delivery systems with particular emphasis on their use in surgical oncology and cardiovascular disorders. It examines the basic principles of drug delivery, innovations of nanotechnology-based systems, and novel therapeutic approaches that are driving therapeutic medicine into the future. The review also identifies the existing challenges, clinical translation of the issue, and the future perspectives of the development of innovative and effective drug delivery systems.

2. FUNDAMENTALS OF TARGETED DRUG DELIVERY SYSTEMS

2.1 Concept and Principles of Targeted Drug Delivery

Therapeutic agents TDSs are intended to deliver the agents to diseased tissues only and limit their access to normal cells. This method increases the drug efficacy and decreases the systemic toxicity via the control of spatial and temporal drug release. The main idea is that carriers, including nanoparticles, should be employed, which are able to identify a particular biological mark or disease (Edis et al., 2021). These systems do not only enhance pharmacokinetics, bioavailability and therapies precision, but are especially useful in cancer and chronic disease treatment.

2.2 Classification of Drug Delivery Systems

2.2.1 Passive Targeting

Passive targeting is based on the physiological properties of diseased tissues and especially on the enhanced permeability and retention (EPR) effect evident in tumors that enables nanoparticles to concentrate by leaky vascularity and inadequate lymphatic drainage (Hossain et al., 2022). Passive targeting does not entail any particular ligand-receptor interactions, and so, it is an easier but efficient approach. The technique is commonly used in cancer therapy particularly in solid tumors that have abnormal vascular structure, which allows drugs to be retained and accumulate.

2.2.2 Active Targeting

The active targeting is the functionalization of drug carriers with antibodies, peptides or small molecule ligands with specific receptors on target cells, which increases cellular uptake and specificity. In cardiovascular disease, such a strategy has been applied to inflammatory biomarkers and endothelial dysfunction to provide genes to disease-afflicted locations (Engelen et al., 2022). Active targeting is capable of enhancing the cure of diseases and reducing the occurrence of off-target effects due to the ability of molecular recognition to discover novel approaches to therapy and cancer treatment.

2.2.3 Stimuli-Responsive Systems

Stimulus reactive drug delivery systems are designed in ways that they release therapeutic agents as a result of a certain internal or external stimulus like pH, temperature, enzymes or oxidative stress. Such systems allow targeted and localized release of drugs, which improve the effectiveness of treatment (Figure 1). As an example, the oxidative stress-sensitive system is especially important in cardiovascular diseases, where an increase in reactive oxygen species may cause the release of drugs in the target area (Farias et al., 2017). This form of smart systems is a sophisticated approach to enhancing drug accuracy.

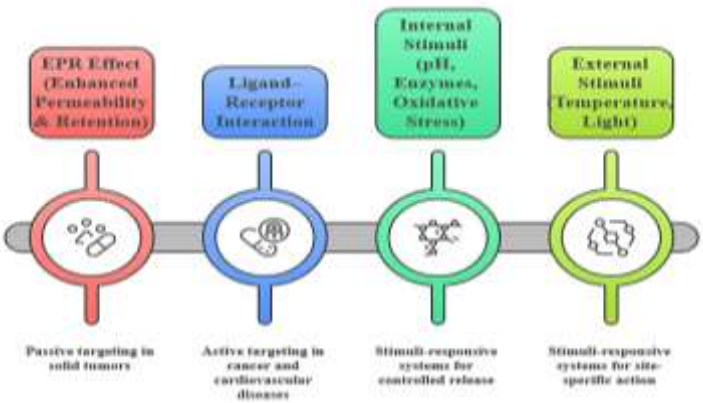

Figure 1. Targeting Modalities in Nanotechnology-Based Drug Delivery Systems

2.3 Biological Barriers to Drug Delivery

The microenvironment of the tumor is very challenging as it is heterogeneous and complex i.e. hypoxia and acidic pH and dense extra-cellular matrix make drug penetration and distribution difficult. Moreover, the contact of tumor cells with the surrounding stromal elements forms a protective niche which restricts therapy performance. Such obstacles make it mandatory to have sophisticated delivery mechanisms that are able to adjust to such a dynamic state so as to have an effective drug build up and effect. The vascular and endothelial barriers control the movement of drugs to the target tissue and usually inhibit the therapeutic action because of structural defects. Endothelial dysfunction and fibrosis in cardiovascular diseases may strongly limit drug penetration, and they decrease treatment efficacy. Selecting fibroblasts and regulating tissue remodelling have become the future potential solutions to improve delivery across these barriers, especially in cardiac diseases with fibrosis and structural remodelling (Gourdie et al., 2016). The immune system serves as a significant protection against foreign particles, such as nanocarriers, and can remove the particle via various pathways, such as the absorption of macrophages and retrieval by the reticuloendothelial system. Such a fast excretion cuts down on circulation time and restricts the availability of drugs at the targets sites. In an attempt to address this, surface modifications are commonly performed on nanocarriers to avoid immune response and increase biocompatibility, consequently increasing therapeutic efficiency and stability in the systemic circulation (Ho et al., 2016).

3. Nanotechnology-Based Drug Delivery Platforms

3.1 Polymeric Nanoparticles

One of the most widely researched drug delivery systems is polymeric nanoparticles which are versatile, biocompatible, and able to release the drug in a controlled manner. They are developed with biodegradable polymers that can entrap different therapeutic agents (Kumari et al., 2016). They can be designed to have increased targeting and longer circulation. Moreover, polymeric systems provide a chance to co-deliver chemotherapeutics and natural compounds, which greatly enhance their therapeutic efficiency (Li et al., 2022).

3.2 Liposomes and Lipid-Based Carriers

Liposomes and lipid-based carriers are systems of lipid bi-layers that are vesicular and have the ability to entrap both hydrophilic and hydrophobic drugs. These carriers enhance systemic toxicity down and drug stability, solubility and bioavailability (Iravani & Varma, 2022). They have a structural similarity to biological membranes, which increases their uptake into cells, and thus they are especially useful in targeted delivery. The applications of these systems are mainly in cardiovascular and oncology therapy because of their capability of delivering sustained and location-specific drug release.

3.3 Dendrimers and Micelles

Clearly, dendrimers are anarchically controlled, highly branched nanostructures that can be loaded with drugs and surface-functionalized with great precision. They are multivalent in nature and enabled the targeting ligands to be attached to them, which increases their specificity and therapeutic effectiveness (Jahangirian et al., 2017). Equally, micelles are amphiphiloic carriers that form themselves in aqueous solutions and enhance the solubility of hydrophobic drugs. These two systems are important in the targeted cancer therapy because they increase drug stability and delivery efficiency.

3.4 Inorganic Nanoparticles (Gold, Silica, Magnetic)

Inorganic nanoparticles e.g. gold, silica and magnetic particles have peculiar physicochemical characteristics supporting therapeutic and diagnostic services. Such nanoparticles allow applying multifunctional methods, such as photothermal therapy and targeted drug delivery via magnets (Kalaydina et al., 2018). They have a high surface area and can be tuned and effectively loaded with drugs, and their properties make them useful building blocks of a theranostic system.

3.5 Hydrogels and Biomaterial-Based Systems

Hydrogels are 3-d polymeric networks that can absorb large quantities of water such that they can be used to carry drugs on a local and controlled basis. Such systems are biomaterial-based and can be induced to react to environmental changes like temperature or PH to allow controlled release of drugs. Advanced nanotechnology-based tools also take into consideration the principles of green nanomedicine to make delivery of drugs more biocompatible and sustainable in the application (Jahangirian et al., 2017).

3.6 DNA and RNA-Based Nanocarriers

Nanocarriers based on DNA and RNA are another new format of targeted drug delivery because of the programmable structures of nucleic acids. With the help of these systems, it is possible to design carriers that are highly specific and can react to the molecular stimuli in biological systems (Hu et al., 2018). They find application specifically in gene therapy, in which RNA-based delivery systems including siRNA and mRNA give specific control over gene expression and hold therapeutic promise.

3.7 Exosomes and Biological Vesicles

Exosomes and biological vesicles are naturally found nanocarriers that are used in intercellular communication. Their natural fit with the human body and their capacity to avoid immune surveillance make them extremely useful in delivering drugs at the targeted location (Table 1). The combination of artificial intelligence and nanoparticle-based systems also improves the specificity of the targeting, especially in cardiovascular diseases (Kamali et al., 2025). Such biological carriers are also being heavily investigated in the delivery of drugs, proteins and genetic material with increased efficacy and reduced toxicity.

Table 1. Nanotechnology-Based Drug Delivery Platforms

Platform	Key Features	Advantages	Applications	Key References
Polymeric Nanoparticles	Biodegradable polymer-based carriers	Controlled release, high stability, co-delivery capability	Cancer therapy, combination therapy	Kumari et al., 2016; Li et al., 2022
Liposomes & Lipid-Based Carriers	Lipid bilayer vesicles	Biocompatibility, enhanced solubility, reduced toxicity	Oncology, cardiovascular diseases	Iravani & Varma, 2022
Dendrimers & Micelles	Branched polymers and self-assembling amphiphiles	High drug loading, improved solubility, targeting flexibility	Targeted cancer therapy	Jahangirian et al., 2017
Inorganic Nanoparticles	Gold, silica, magnetic particles	Multifunctionality, imaging + therapy (theranostics)	Photothermal therapy, targeted delivery	Kalaydina et al., 2018
Hydrogels & Biomaterials	3D polymer networks	Localized delivery, stimuli-responsive release	Tissue engineering, localized therapy	Jahangirian et al., 2017
DNA/RNA Nanocarriers	Programmable nucleic acid structures	High specificity, gene regulation capability	Gene therapy, precision medicine	Hu et al., 2018
Exosomes & Biological Vesicles	Natural cell-derived vesicles	High biocompatibility, immune evasion	Drug/gene delivery, regenerative medicine	Kamali et al., 2025

4. Targeted Drug Delivery in Surgical Oncology

4.1 Role of Targeted Delivery in Cancer Surgery

Delivery of drugs directly to the tumor is highly imperative in optimizing the success of cancer surgery by increasing accuracy in the destruction of tumors and reducing the harm caused to the healthy tissues. Complex delivery systems enable treatment of therapies on site prior to, during or following surgery and this results in minimized systemic toxicity and enhanced healing. Combining deliberate measures with surgical oncology has also shown a huge enhancement in the effectiveness of treatment, especially in complex tumors, in which precision medicine interventions are necessary to maximize the effect of therapy (Li et al., 2023).

4.2 Tumor-Specific Targeting Strategies

The ligand-receptor targeting is based on the utilization of dedicated ligands that bind to the overexpressed receptors on tumor cells and allow any form of accumulation of the drug to occur at the tumor site selectively. This increases the cellular uptake and decreases off-target effects. The tumor cells usually have their own molecular signatures and targeted systems can take advantage of the differences to deliver drugs directly onto the tumor. These approaches are essential to enhance the specificity and efficacy of treatment of cancer (Liu et al., 2024). Antibody-based delivery involves the use of monoclonal antibodies that are conjugated with an agent of therapy and are used to identify and bind tumor associated antigens specifically. This plan increases the accuracy of targeting and becomes direct drug delivery to the cancerous cells. Antibody-drug conjugates have demonstrated considerable potential in enhancing the treatment effects and decreasing systemic toxicity, which is why they can be regarded as a useful method in contemporary oncotherapy with taking advantage of the specific biochemical context of tumors, including acidic pH and high levels of enzyme activity (Li et al., 2023). These stimuli-sensitive systems allow controlled release of drugs in the tumor microenvironment to improve drug therapy. Smart drug delivery systems with the ability to react to these internal cues have been shown to have a huge potential in enhancing targeted cancer treatment (Liu et al., 2016).

4.3 Nanocarriers for Chemotherapy Enhancement

Nanocarriers have also played a major role to improve the effectiveness of chemotherapy by increasing the drug solubility, stability as well as targeted delivery. In these systems, it is possible to accumulate more drugs at the tumor sites with minimum exposure to the system. Multifunctional nanoparticles also allow combined therapeutic modalities, such as chemotherapy, phototherapy and immunotherapy, and consequently enhance the overall treatment outcomes. These developments have made traditional chemotherapy an effective method of treatment that is precise (Li et al., 2024).

4.4 Co-delivery Systems and Combination Therapy

The co-delivery systems allow the concomitant delivery of two or more therapeutic agents like chemotherapeutic drugs or gene therapies in order to realize synergistic effects. The method improves the effectiveness of treatment by altering the various pathways involved in tumor development. Multipurpose nanoparticle-based systems have been created to serve combination therapy to enhance treatment response and to diminish/lessen drug resistance. These systems will be a promising future of cancer treatment methods (Li et al., 2024).

4.5 Overcoming Drug Resistance and Tumor Recurrence

The resistance to drugs and recurrence of tumors are the critical issues in surgical oncology. Targeted drug delivery systems are useful to address these problems as they allow the release of the drug in a sustained and localized manner hence, keeping therapeutic levels of drugs at the tumor site. Moreover, there are improved delivery systems that can

overcome the resistance mechanisms like drug efflux and metabolic breakdown. These issues are critical to overcome and positively affect the long-term patient outcome and the minimization of recurrence rates after surgical operations (Mahvi et al., 2018).

4.6 Localized Drug Delivery in Post-Surgical Settings

Delivery of drugs locally in the post-surgical environment is aimed at preventing tumor recurrence and tissue healing. Formulations that use implantable delivery systems, hydrogels, and nanoparticles can be delivered directly to the operative area and guarantee the sustained release of the drug and reduce systemic drug side effects (Figure 2). New methods, such as exosome-based delivery systems, have a better biocompatibility and targeting ability, and they can be considered a good option in post-surgical cancer therapy (Li et al., 2025).

Figure 2. Targeted Drug Delivery in Surgical Oncology

5. Targeted Drug Delivery in Cardiovascular Disorders

5.1 Pathophysiological Basis and Targeted Therapeutic Approaches

The multi-faceted processes that cause cardiovascular diseases include endothelial dysfunction, inflammation, oxidative stress, and abnormal cellular signaling, which as a collective entity form certain therapeutic intervention targets. The targeted drug delivery systems are developed to take advantage of the existence of the following specific pathological features and allow accumulation of a drug in a specific location and minimizes systemic toxicity (Omidian et al., 2023). Also, the progress in the drug delivery technologies that was initially created to target cancer has given useful information on enhancing the efficiency and precision of targeting (Reddy & Reddy, 2025).

5.2 Nanomedicine in Atherosclerosis, Vascular Diseases, and Myocardial Infarction

Nanomedicine has played a very important role in ensuring that atherosclerosis and vascular disorders are treated better through the delivery of therapeutic agents to the diseased tissues specifically. Nanoparticles have the ability to be concentrated specifically in the atherosclerotic plaques to deliver drugs that inhibit inflammation and lipid deposition (Pala et al., 2020). These systems in myocardial infarction support local application of cardioprotective agents, reduce tissue damage and increase repair. Another role is played by liposomal drug delivery systems that enhance stability and regulated release of drugs resulting in increased therapeutic efficacy (Olusanya et al., 2018).

5.3 RNA-Based, Gene Delivery, and Advanced Therapeutic Strategies

Gene delivery methods and RNA-based delivery are a paradigm shift in the treatment of the heart as they allow the specific regulation of the expression level of genes. Nanocarriers maintain nucleic acids including siRNA and mRNA and deliver them in a targeted manner to specific cells to enhance therapies. Furthermore, nanoparticle systems of co-delivery enable delivery of multiple therapeutic agents at the same time, which leads to improved treatment efficacy due to the synergistic process (Qi et al., 2017). These approaches are being translated into cardiovascular applications more and more and are based on oncology.

5.4 Targeting Inflammation, Oxidative Stress, and Regenerative Therapy

Oxidative stress and inflammation play a major role in the progression of cardiovascular diseases and are also important therapeutic targets. Specific delivery mechanisms allow local application of anti-inflammatory and antioxidant agents, which is more precise in treatment and less side effects of the systemic effects (Table 2). Moreover, the regenerative therapies like cardiac tissue engineering combine the use of biomaterials and drug delivery system to facilitate tissue repair and functional recovery. Regenerative outcomes can be improved using advanced nanotechnology-based systems, including systems that are based on a more general biomedical use (Passeri et al., 2022; Razavi et al., 2024).

Table 2. Targeted Drug Delivery Strategies in Cardiovascular Disorders

Category	Key Mechanism/Approach	Therapeutic Benefit	Applications	Key References
Pathophysiological Targeting	Targeting inflammation, oxidative stress, endothelial dysfunction	Site-specific delivery, reduced toxicity	General cardiovascular diseases	Omidian et al., 2023; Reddy & Reddy, 2025
Nanomedicine (Atherosclerosis & MI)	Nanoparticle accumulation in plaques and ischemic tissue	Reduced inflammation, improved repair	Atherosclerosis, myocardial infarction	Pala et al., 2020; Olusanya et al., 2018
RNA & Gene Delivery	siRNA/mRNA delivery via nanocarriers	Gene regulation, precision therapy	Cardiovascular genetic disorders	Qi et al., 2017
Inflammation & Oxidative Stress Targeting	Anti-inflammatory and antioxidant delivery	Reduced disease progression	Chronic cardiovascular conditions	Pala et al., 2020
Regenerative & Tissue Engineering	Biomaterials + drug delivery systems	Tissue repair, cardiac regeneration	Cardiac remodeling, heart failure	Passeri et al., 2022; Razavi et al., 2024

6. Advanced and Emerging Therapeutic Strategies

6.1 Smart and Stimuli-Responsive Drug Delivery Systems

Smart drug delivery systems are designed to release therapeutic agents in response to predefined internal or external stimuli e.g. pH, temperature, enzymes or redox. The systems are also precise in that the drug is released at the target site, which reduces the toxicity of the systemic organs and increases the effectiveness of the therapy (Tibbitt et al., 2016). Responsive platforms can be particularly useful in chronic and metabolic conditions, where dynamism on the physiological level demands adaptive delivery systems (Shi et al., 2019).

6.2 AI-Integrated Drug Delivery Design

One of the newly developed tools that has allowed remaking the design and optimization of drug delivery systems is artificial intelligence (AI). The AI-based models are able to forecast the drug-carrier interaction, optimize the properties of nanoparticles and tailor therapeutic approaches basing on patient-specific data. The developments enhance the effectiveness of targeting and save the development time. Artificial intelligence combined with nanotechnology is a growing area of cardiovascular and other complicated disease interventions, and it presents novel possibilities of precision medicine (Singh et al., 2024).

6.3 Multifunctional and Theranostic Nanoparticles

Multifunctional nanoparticles are nanoparticles that are engineered to carry out both therapeutic and diagnostics functions on one platform, that is, to treat and monitor diseases at the same time. These theranostic systems enable real time imaging, local delivery and measurement of response to therapy (Sim & Wong, 2021). These platforms have already shown great potential to improve the accuracy of the treatment process and allow early detection, especially in complicated illnesses where the patient should undergo constant monitoring (Singh et al., 2019).

6.4 Nano-enabled Delivery of Natural Bioactives

Nanotechnology has made natural bioactive compounds easy to deliver because of the limitation, which include lack of solubility and low bioavailability. Nanoformulations can increase stability and drug delivery of phytochemicals and other natural agents. As an example, addition of bioactives such as hesperidin into gold nanoparticles has been reported to have better anticancer and anti-inflammatory properties, which show enhanced biocompatibility and targeted functionality (Sulaiman et al., 2020). These treatments provide hopeful substitutes of traditional treatment.

6.5 Personalized and Precision Medicine Approaches

The use of personalized medicine combines complex drug delivery systems and individualized differences in patients, including genetic profile, the conditions of the disease, and biomarker expression, to maximize therapeutic outcomes. Systems based on nanotechnology allow delivering drugs in specific ways enhancing their efficacy and decreasing adverse effects (Figure 3). The use of biomaterial-based systems also contributes to personalization as it enables regulated and flexible delivery of drugs (Trucillo, 2024). These methods are a great step forward in the field of the new healthcare, where the methods of treatment are adjusted to the needs of patients and characteristics of diseases.

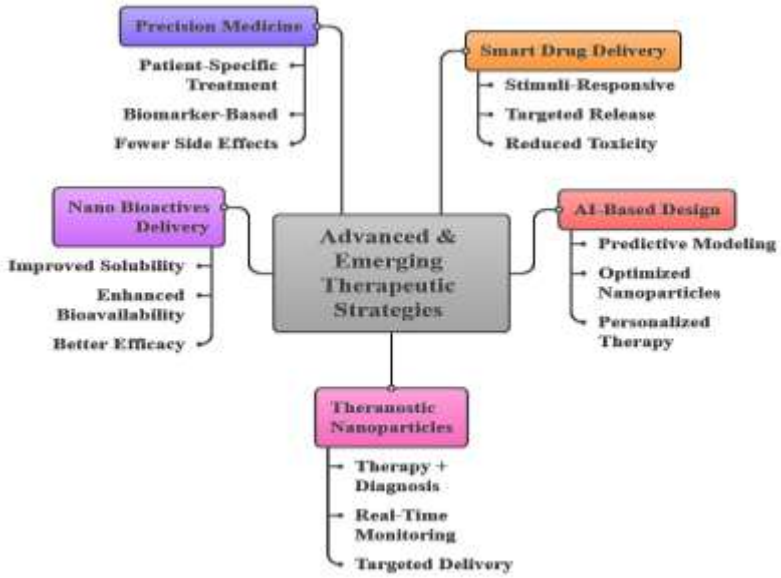

Figure 3. Advanced and Emerging Therapeutic Strategies in Drug Delivery

7. Clinical Translation and Current Applications

7.1 Clinically Approved Targeted Drug Delivery Systems

The targeted drug delivery system has been developed using clinical translations resulting in a number of approved formulations that enhance therapeutic effectiveness and safety. Polymeric nanocarriers and liposomal formulations are to be considered nanoparticle-based systems that have been shown to have improved drug stability, regulated release, and targeted accumulation at disease locations (Yetisgin et al., 2020). Also, PEG-based hydrogel has been revealed to be useful in the localized delivery of drugs in cancer therapy as they provide sustained-release and enhanced biocompatibility (Wang et al., 2023). These innovations put emphasis on the increased clinical applicability of targeted delivery technologies.

7.2 Ongoing Clinical Trials in Oncology and Cardiovascular Diseases

Current clinical trials are being conducted on the effectiveness and safety of modern drug delivery systems in cancer and heart diseases. Polymer nanocarriers and gene delivery systems are under investigation because of their capacities to improve precision of therapy and improve systemic toxicity (Xia et al., 2021). Nanoparticle-based delivery systems are being clinically evaluated as targeted therapies of atherosclerosis and myocardial diseases in cardiovascular disorders, and they have a promising translational potential (Yang et al., 2022). The studies are essential in closing the gap between laboratory and clinical application research.

7.3 Regulatory Considerations and Safety Challenges

Although there are notable improvements, there are a number of regulatory and safety issues that are presenting problems with clinical adoption of targeted drug delivery systems. Long-term toxicity, immunogenicity, and pharmacokinetics variability are only some of the issues that should be carefully considered before approval. The high level of interactions between nanoparticles and biological systems makes their systems focus on stricter regulatory assessment, which accelerates the measure of safety and efficacy (Yao et al., 2020). Moreover, currently used therapeutic methods such as the traditional treatments of cancer still pose some limitations that require the establishment of safer and more efficient delivery methods.

7.4 Patient Adherence and Real-World Applications

The issue of patient adherence and real-world applicability are the most important aspects of targeted drug delivery systems. High-technology delivery systems enhance the adherence to the treatment by lowering the dose frequency and adverse events (Table 3). Specific nanoparticles can assist in improving treatment because they lead to effective drug delivery to particular tissues and, hence, improved patient experience and treatment outcomes (Yetisgin et al., 2020). With the further development of these systems, their further incorporation into the everyday clinical practice is likely to enhance the process of disease management and overall healthcare results greatly.

Table 3. Clinical Translation and Applications of Targeted Drug Delivery Systems

Category	Key Aspect	Clinical Benefit	Applications	Key References
Clinically Approved Systems	Polymeric nanoparticles, liposomes, PEG-based hydrogels	Improved stability, controlled release, reduced toxicity	Cancer therapy, localized delivery	Yetisgin et al., 2020; Wang et al., 2023
Ongoing Clinical Trials	Nanocarriers, gene delivery systems	Enhanced precision, reduced systemic side effects	Oncology, cardiovascular diseases	Xia et al., 2021; Yang et al., 2022

Regulatory & Safety Challenges	Toxicity, immunogenicity, pharmacokinetics variability	Ensures safety, efficacy, regulatory compliance	All targeted DDS applications	Yao et al., 2020
Patient Adherence & Real-World Use	Reduced dosing frequency, improved targeting	Better compliance, improved outcomes	Chronic disease management	Yetisgin et al., 2020

8. Challenges and Limitations

Even though targeted drug delivery systems have a high therapeutic potential, they have several challenges that restrict their extensive clinical use. Among the major issues is toxicity and bio-compatibility since nanocarriers can cause immune reactions, oxidative stress, or get deposited in key organs, which can have long-term negative outcomes. Their interaction with the biological system may go dangerous due to their variability in physicochemical parameters including size, surface charge, and composition, which further supports the importance of safer alternatives to conventional therapeutics (Zafar et al., 2025). Besides the issue of safety, scale-up and manufacturing limitations are also very significant barriers to clinical translation. The design of nanocarriers demands a very high level of control of the parameters (particle size, drug loading and kinetics of release) which grows more complex in large-scale production. Such complexities frequently lead to reproducibility, stability and regulatory compliance problems that eventually slows the commercialization process and reduces accessibility. Moreover, high targeting efficiency is an important issue since biological variation and dissimilar tissue backgrounds may decrease drug delivery systems specificity. Poor targeting can result in off target-accumulation, which reduces therapeutic efficacy, and elevates off side effects (Figure 4). Learning how to target tissues and enhance precision in delivery methods are then important to maximize treatment results (Zhao et al., 2020). Accessibility and economic factors also limit the use of modern methods of drug delivery. The cost of research and development, complicated manufacturing procedures and strict regulatory standards lead to the high cost of therapies that cannot be readily available in low-resource environments. Furthermore, some specialized systems like nanoparticle-based oral delivery systems need to have sophisticated infrastructure and knowledge which further restricts their practical use (Zhang and Merlin, 2018). All these issues together indicate that more research and innovation is needed to advance the safety, scalability, efficiency, and accessibility of targeted drug delivery systems.

Figure 4. Barriers in Targeted Drug Delivery

9. Future Perspectives

The future of targeted drug delivery systems is likely to be radically changed as the next-generation nanomedicine is developed, which puts more stress on precision, versatility and reactivity to the complicated biological surroundings. New platforms will be able to integrate multifunctional nanocarriers that can be used to diagnose, do targeted therapy and real-time monitoring, thus enhancing patient outcomes and the accuracy of treatments. Such sophisticated systems will probably be aimed at surpassing the current physical obstacles, increasing drug bioavailability, and stimuli-response, and controlled release of drugs depending on the particular circumstances of disease. It is expected that the combination of biotechnology and genomics also will continue to be used to revolutionize the process of drug delivery by providing therapies tailored based on the genetic composition, molecular profile, and disease pathogenesis of an individual. With this convergence, it will be easier to design very personalized treatment plans, especially in complex conditions like cancer and cardiovascular conditions, where patient specific variability is a vital factor in treatment effectiveness. The new technologies of gene editing, RNA-based therapeutics and biomarker-based targeting methods will likely play a role in this changing landscape.

Translational research will be instrumental towards the translation of these innovations in the laboratory to clinical practice. This gap cannot be bridged through technology alone, but rather through solid clinical validation, regulatory backing and scalable production. The interaction between the academic community, industry, and health facilities will be critical in speeding up the creation and acceptance of new drug delivery systems, their safety, effectiveness, and availability to more significant groups of patients. Moreover, interdisciplinary strategies will have a significant influence on the future of drugs delivery. Combination of nanotechnology, bioengineering, artificial intelligence, material science, and clinical medicine will contribute to the creation of new solutions that will address existing constraints. These

partnerships will make it possible to design more intelligent delivery technologies, enhance predictive drug behavior modeling, and non-invasive optimization of treatment. All in all, these developments are likely to transform the future of the modern medical field by providing more effective, tailor-made, and patient-centered treatment options.

10. CONCLUSION

Targeted drug delivery systems (TDDS) have become an innovative technique of contemporary therapeutics, which can counteract the severe deficiencies of the traditional drug delivery system like low specificity, systemic toxicity, and low efficacy. This review has emphasized that nanotechnology has played a great role in improving drug delivery platforms, such as polymeric nanoparticles, liposomes, dendrimers, hydrogel and nucleic acid-based carriers, allowing the control of release and the increase in bioavailability. One of the major conclusions is that site-specific drug accumulation with the aid of targeted strategies has been significantly enhanced, especially in the case of oncology and cardiovascular diseases with the usage of passive, active, and stimuli-responsive systems. TDDS have shown great promise in the field of surgical oncology and have been used to moderate chemotherapy, allow combination therapy, deal with drug resistance, and decrease the risk of tumor recurrence by means of local and precision-based treatment. Equally, nanomedicine has enabled targeted therapeutic intervention of atherosclerosis, myocardial infarction, inflammation in cardiovascular diseases, and application of gene delivery and regeneration methods have provided novel therapeutic opportunities. The accuracy and flexibility of these systems is further enhanced by the emerging technologies such as AI-integrated design, theranostic nanoparticles and a personalized medicine. In spite of these developments, toxicity, scalability, regulatory issues, and accessibility are some of the major challenges facing the widespread application of clinical implementation. The only way to overcome these limitations is by conducting interdisciplinary studies and translational work. Altogether, TDDS is a promising field of precision medicine, which promises better treatment, fewer side effects, and better patient-centred therapies in a variety of clinical contexts.

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