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Targeted Drug Delivery Systems: Advances and Challenges in Medicinal Chemistry

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Abstract:

The concept of targeted drug delivery systems (TDDS) is one of the greatest inventions in the field of medicinal chemistry allowing the selective drug delivery to diseased tissues avoiding potential systemic toxicity and improving the therapeutic efficacy. This review article gives a thorough presentation of the fundamentals, recent developments and human clinical application of TDDS with an accent on liposomes, polymeric nanoparticles, antibody–drug conjugates (ADCs), ligand-based drug delivery systems and novel smart nanocarriers. Human clinical data shows that such innovative delivery systems enhance pharmacokinetics of the drugs, their bioavailability, release from carrier and overall therapeutic effect in several diseases, including cancers, cardiovascular diseases, neurological disorders, diabetes, autoimmune diseases and infectious diseases. The review presents the advantages and disadvantages of modern TDDS technology and the major obstacles in the field, including biological barriers, safety issues, manufacturing complications, regulations and clinical translation of these technologies. The increasing use of artificial intelligence, precision medicine, gene and RNA therapeutics and biomarker-based drug delivery is highlighted. Therefore, TDDS are promising therapeutic systems improving medicinal chemistry through safer and more effective and personalized treatment of diseases.

Keywords: Targeted Drug Delivery Systems; Medicinal Chemistry; Liposomes; Polymeric Nanoparticles; Antibody–Drug Conjugates (ADCs); Precision Medicine.

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1. INTRODUCTION

The targeted drug delivery systems have proved to be one of the most remarkable inventions in medicinal chemistry due to their ability to deliver drugs selectively to diseased tissues or cells or specific molecular targets without affecting healthy body parts. Targeted drug delivery is a great innovation compared to conventional drug delivery methods since it helps in delivering drugs in an effective manner, unlike traditional methods where bioavailability is low and there is drug

distribution nonspecifically, more dosing requirements, and also systemically adverse effects on the body[1]. The rapid growth in nanotechnology, biomaterials, pharmaceutical science, and molecular biology has helped in developing advanced delivery systems such as liposomes, polymeric nanoparticles, antibody–drug conjugate (ADCs), lipid nanoparticles, ligand-targeted delivery, and stimuli-responsive nanoparticles. These technologies have significantly enhanced drug stability, pharmacokinetic performance, and therapeutic precision, making them valuable tools in the treatment of various human diseases and advancing the field of precision medicine.

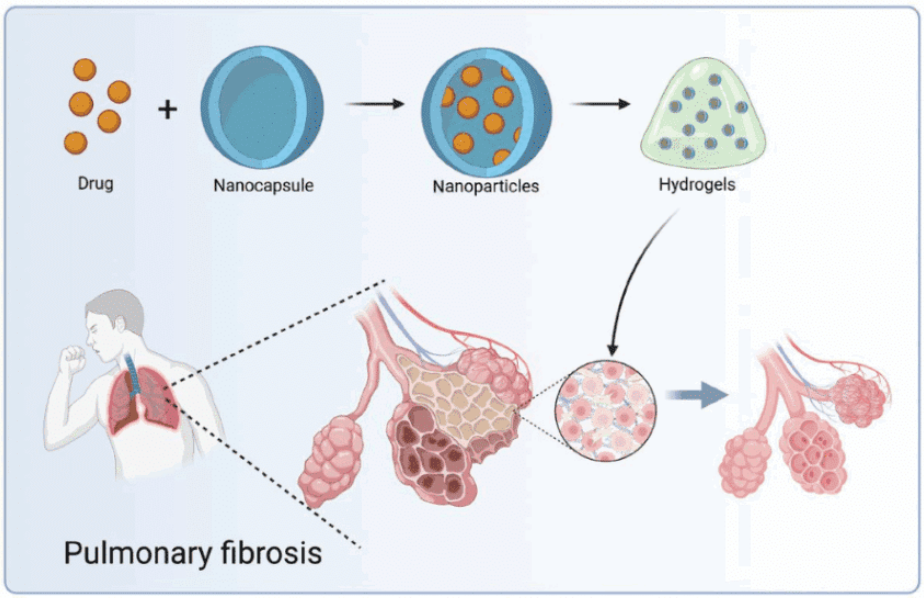

Figure 1: Targeted drug delivery systems (TDDS)[2]

Current advancements in targeted drug delivery have found application in the clinic for oncology, cardiovascular diseases, neurodegenerative diseases, diabetes, autoimmune diseases, and infectious diseases. Clinical studies in humans have revealed that targeted delivery strategies increase drug localization, decrease systemic toxicity, facilitate adherence to the treatment regime, and offer overall improvement in the results of therapy as compared to conventional therapy regimens[3]. Moreover, the implementation of technologies such as artificial intelligence, biomarkers, molecular imaging, gene therapy, and RNA-based therapy has led to faster development of advanced delivery techniques that will help achieve personalized medicine. However, despite the above progress in this field, there are biological, safety, manufacturing, regulatory, and translational hurdles that prevent some of the emerging delivery techniques from gaining wider acceptance.

1.1 Background Information and Context

Medicinal Chemistry is an integral part of the process of developing medicinal substances for use in therapy, although the efficiency of some medicines does not depend solely on their biological activity, but on their capability of reaching the place of its activity. In traditional drug delivery systems, there often occurs the problem of low target specificity, poor bioavailability of drugs, drug instability, and the presence of side effects that may limit the therapeutic potential of these drugs[4]. Targeted drug delivery systems have overcome many of the limitations associated with traditional systems by providing selective transportation of drugs, controlled release, and increased localization of medicines in diseased tissues. As a result, these delivery platforms have become increasingly important in improving treatment outcomes, reducing drug toxicity, and supporting the advancement of precision medicine.

1.2 Objectives of the Review

The main aims of the current review are:

- To describe the basic concepts and common approaches to targeted drug delivery employed in medicinal chemistry.
- To consider the recent human clinical uses of targeted drug delivery systems in cancer, cardiovascular diseases, neurodegenerative diseases, diabetes, autoimmune diseases, and infections.
- To assess the recent developments in the field of targeted drug delivery methods, such as liposomes, polymeric nanoparticles, antibody-drug conjugates, ligand-targeted drug delivery, and intelligent nanoparticles
- To discuss the advantages, drawbacks, and current issues in translating the targeted drug delivery systems into clinical practice.
- To determine the existing research gaps and future prospects in developing targeted drug delivery with the help of artificial intelligence, precision medicine, and other novel therapies.

1.3 Importance of the Topic

The rising global burden of cancers, heart diseases, neurodegenerative diseases, diabetes, autoimmune diseases, and infections has resulted in a critical demand for safer and effective drugs which are also highly specific and targeted. The use of targeted drug delivery systems has contributed immensely to modern-day medicine through increased drug specificity, minimized toxicity, higher therapeutic effect, and customized treatment methods[5]. Their application along with nanotechnology, molecular targeting, artificial intelligence, and precision medicine can

revolutionize the management of diseases through controlled release of drugs and custom treatment options. It is important to understand the advancements, applications, challenges, and future of the targeted drug delivery systems to promote further research in medicinal chemistry and facilitating their successful translation into routine clinical practice.

2. TARGETED DRUG DELIVERY SYSTEMS: PRINCIPLES AND CLINICAL ADVANCES

Targeted drug delivery technology has made great advances in modern medicinal chemistry, where drug delivery is made selective to diseased tissue while avoiding damage to healthy tissue[6]. In contrast to other traditional drug delivery systems, targeted drug delivery systems help in improving the effectiveness, bioavailability, and patient safety by achieving specific and regulated drug delivery. Recent human clinical studies have proved that targeted drug delivery systems are highly effective in treating cancers, cardiovascular diseases, neurological problems, autoimmune diseases, and infectious diseases. Numerous drug delivery technologies like liposomes, polymeric nanoparticles, ADCs, ligand targeting drug delivery system, and smart nanoparticles have advanced from research lab to clinics. This part of the article will deal with different kinds of drug delivery systems and will discuss their methods of action, therapeutic uses, advantages, and disadvantages, especially from human clinical studies.

2.1 Fundamentals of Targeted Drug Delivery

Targeted drug delivery is defined as selective delivery of drugs to particular tissues, cells or molecular targets, without distributing them throughout the body system. The key purpose is to increase the efficacy of treatment, decrease adverse effects and improve compliance due to controlled release of drugs[7]. Recently carried out clinical trials on humans have shown that the targeted drug delivery positively affects pharmacokinetics parameters, increases the amount of accumulated drugs at diseased site and decreases the systemic toxicity of drugs in comparison with traditional delivery systems. Various methods used in clinical trials include randomized controlled trials, pharmacokinetics/pharmacodynamics assessments, medical imaging for biodistribution evaluation and safety studies. These studies consistently reported improved therapeutic outcomes, prolonged circulation time, enhanced bioavailability, and better clinical responses across multiple disease conditions.

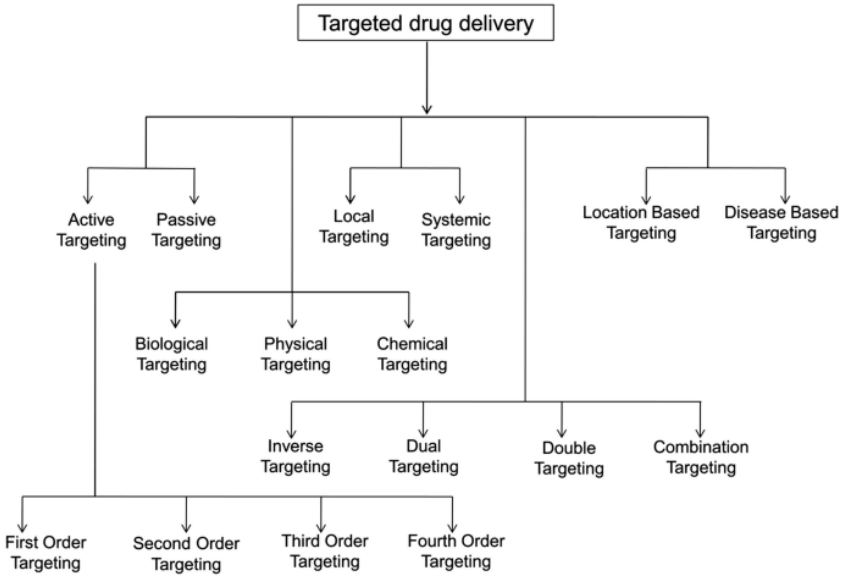

Figure 2: Fundamentals of Targeted Drug Delivery[8]

Strengths

- Site specific drug delivery
- Low systemic toxicity
- Increased drug efficacy
- Improved pharmacokinetics and pharmacodynamics
- Increased patient compliance due to drug release control

Weaknesses

- Complicated drug delivery system formulation
- High manufacturing cost
- Drug accumulation biological barriers
- Heterogeneity in drug response among patients
- Regulatory issues for clinical translation

2.2 Liposomal Drug Delivery Systems

Liposomes have been found to be the most intensely researched and clinically approved delivery mechanisms for drug delivery owing to their high biocompatibility and capability to incorporate both lipophilic and hydrophilic drugs[9]. There have been clinical trials carried out on humans that

show the effective use of liposomes in treating breast cancer, ovarian cancer, pancreatic cancer, leukemia, and infections caused by fungi using drugs like liposomal doxorubicin, liposomal irinotecan, and liposomal amphotericin B. The common methods used include multicenter randomized clinical trials, prospective cohort studies, pharmacokinetic studies, survival analysis, and side effect evaluation. Such studies have conclusively shown better drug uptake into diseased cells, increased circulation time, reduced cardiotoxicity, reduced toxicity, and increased progression free survival rates when compared with conventional drugs.

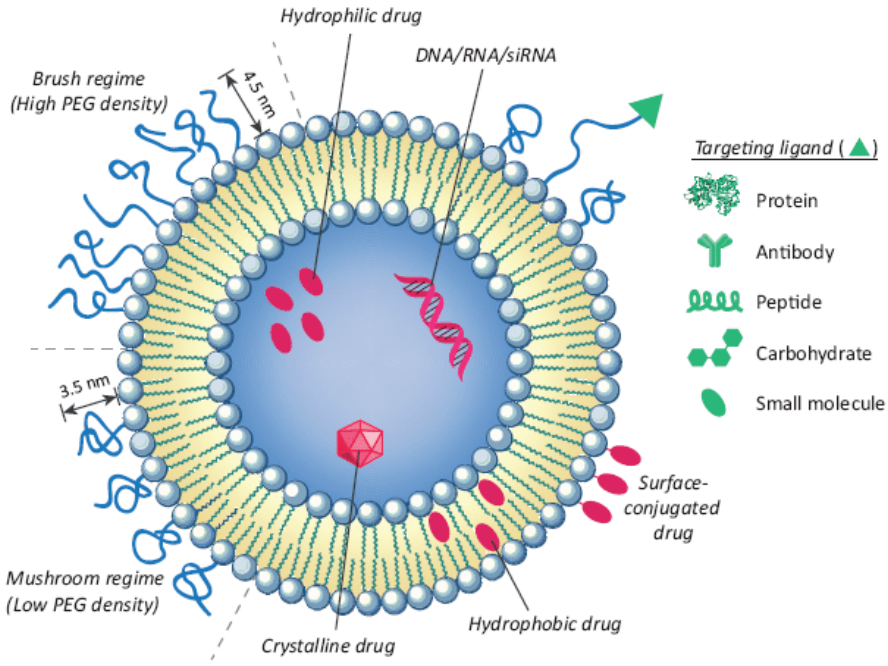

Figure 3: Liposomal Drug Delivery Systems[10]

Strengths

- Biocompatibility
- Drug delivery control
- Low systemic toxicity
- Increase in stability of drugs
- Several commercially available formulations

Weaknesses

- Limited drug-loading efficiency
- Stability issues during storage

- High manufacturing costs
- Variable tissue penetration
- Potential rapid clearance without surface modification

2.3 Polymeric Nanoparticles

The emergence of polymeric nanoparticles as drug carriers is attributed to their biodegradability, drug release ability, and surface modification capability. Clinical studies in humans have recently been conducted on the application of polymeric nanoparticles in treating cancer, eye disease treatments, cardiovascular problems, and metabolic disorders[11]. The majority of the studies made use of clinical trials, pharmacokinetics, controlled release, and imaging to measure biodistribution and therapeutic efficacy. Clinical results have revealed improved bioavailability of drugs, extended drug efficacy, effective cellular drug delivery, reduction in dosing frequency, and decreased toxicity. Some of the biodegradable polymers include PLGA and PEG.

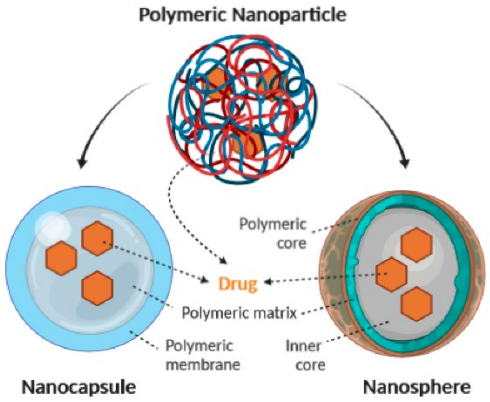

Figure 4: Polymeric Nanoparticles[12]

Strengths

- Good biodegradability
- Controlled drug delivery
- High drug loading capacity
- Easy surface modification
- Enhanced drug stability

Weaknesses

- Complicated manufacturing process

- Variation in batch production
- Scalable manufacturing difficulties
- Polymer degradation variation
- Lack of long-term clinical data

2.4 Antibody–Drug Conjugates (ADCs)

The antibody-drug conjugate is one of the major advancements in targeted drug delivery, where highly active cytotoxic agents are conjugated to monoclonal antibodies with the aid of chemically engineered linkers[13]. The efficacy of the ADCs trastuzumab emtansine, trastuzumab deruxtecan, sacituzumab govitecan, and brentuximab vedotin have been well established in HER2-positive breast cancer, urothelial carcinoma, lymphoma, and triple-negative breast cancer through human clinical trials. Methods utilized in these studies include Phase I-III clinical trials, survival analysis, response analysis, and safety studies. They all concluded that the ADCs have superior efficacy than chemotherapy in terms of response rate, PFS, OS, and less off-target toxicity.

Strengths

- Specific cancer targeting
- Efficacy of therapy
- Lower toxicity on nontarget cells
- Customized patient therapy
- Substantial clinical trials and approval

Weaknesses

- Resistance against drugs
- Expensive treatment
- Inability of linker in some formulations
- Limited usage for patients with biomarkers
- Possible immune adverse effects

3. HUMAN CLINICAL APPLICATIONS OF TARGETED DRUG DELIVERY

The technology of targeted drug delivery has revolutionized the realm of therapeutics by optimizing the delivery of drugs to specific sites, thereby increasing their efficacy and lowering side effects. Many clinical trials in humans have shown that the technology offers numerous

benefits over[14] the traditional drug delivery systems in terms of the increased localization of the drug within diseased tissues without causing any harm to the normal organs. The developments in the fields of nanotechnology, medicinal chemistry, molecular targeting, and precision medicine have led to the clinical application of many targeted drug delivery vehicles such as liposomes, polymeric nanoparticles, antibody-drug conjugates (ADCs), lipid nanoparticles, and ligand-targeting agents[15].

3.1 Cancer Therapy

Targeted drug delivery systems still remain the most successful when used for cancer therapy. Human clinical trials show the ability of targeted delivery systems to increase the delivery of drugs into tumors via passive and active targeting methods while minimizing the toxic effects on the healthy tissues[16]. Various liposomes, antibody-drug conjugates, polymeric nanoparticles, nanoparticles with albumin binding, and ligand-targeted nanoparticles have been tested on patients suffering from breast, lung, colon, ovarian, pancreatic cancers, leukemia, and lymphoma.

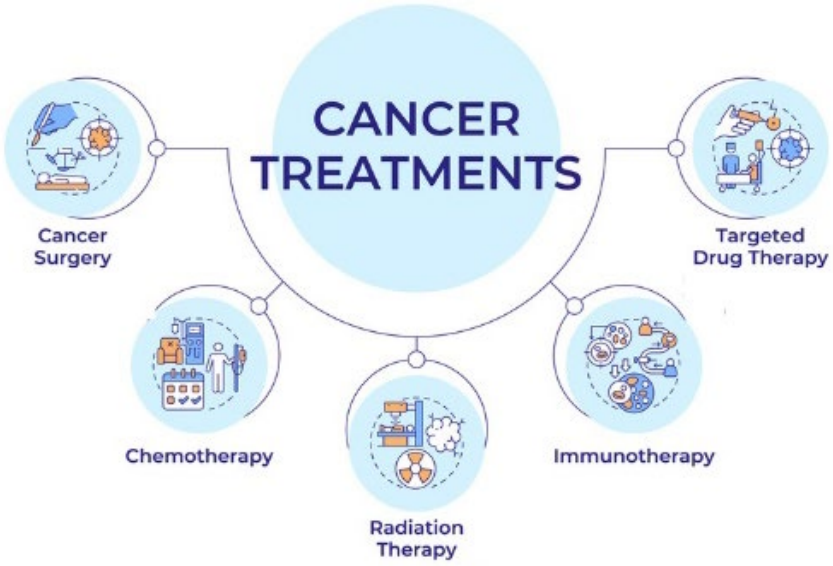

Figure 5: Cancer Treatments[17]

Approved drugs such as liposomal doxorubicin, albumin-bound paclitaxel, trastuzumab emtansine, trastuzumab deruxtecan, sacituzumab govitecan, and brentuximab vedotin show better outcomes in terms of progression-free survival, overall survival, response rates, and quality of life than standard chemotherapy[18]. The human trials have also indicated a lower incidence of cardiotoxicity, neurotoxicity, and system-wide side effects due to the use of targeted therapy for precision medicine. Nonetheless, some limitations like the heterogeneous nature of tumors, drug resistance to several drugs, and variable target receptor expression persist in particular patients.

3.2 Cardiovascular Diseases

Drug delivery is one of the most significant approaches that have been developed for the treatment of cardiovascular diseases because of its capability of delivering the drugs in a selective manner to diseased vascular tissue, atherosclerotic lesions, clots, and ischemic heart[19]. Clinical trials of humans have been conducted using nanoparticles that can deliver thrombolytics, anti-inflammatory agents, anticoagulants, and lipid-lowering agents to improve treatment efficacy while minimizing bleeding complications and systemic toxicity.

Figure 6: Cardiovascular Diseases[20]

The benefits offered by drug-coated stents and nanoparticles as well as their ability to target delivery systems have been established through successful clinical applications by way of minimizing restenosis, promoting endothelial healing, and avoiding repeat blockage of blood vessels[21]. The latest clinical studies have involved research on delivery of targeted therapy via imaging for treatment of myocardial infarctions, heart failure, and peripheral vascular disease. While much success has been achieved, more clinical trials need to be conducted.

3.3 Neurological Disorders

The problem associated with the therapy of neurological disorders is that the blood-brain barrier prevents many therapeutic substances from accessing the central nervous system. This has prompted researchers to develop specific delivery systems for improving the delivery of therapeutic drugs to the brain through the blood-brain barrier[22]. There have been human clinical trials to test the effectiveness of liposomes, polymeric nanoparticles, lipid nanoparticles, receptor-mediated nanocarriers, and intranasal delivery systems for treating neurological disorders such as Alzheimer's disease, Parkinson's disease, glioblastoma, epilepsy, and multiple sclerosis.

The following outcomes have been observed in clinical studies of BBB modification techniques: increased penetration of the drug into brain tissue; improved neurological results; increased circulation time of the drug and decreased systemic side effects. Transferrin and insulin receptor targeting methods have proven to be promising in the clinical application for brain-targeted drug delivery. However, there are a number of obstacles for their clinical implementation.

3.4 Diabetes and Metabolic Diseases

Targeted drug delivery has played a significant role in the management of diabetic and metabolic diseases owing to the enhancement of drug availability, prolonged duration of action, and decreased administration frequency of these medications. Clinical trials in humans have examined the use of nanocrystals in insulin, oral insulin delivery, GLP-1 agonists, and extended release drugs[23].

New findings from clinical studies show that nanodelivery systems offer improved insulin uptake, glucose metabolism, hypoglycemic incidents, and patient compliance when compared with traditional treatments. They can even be used for the delivery of obesity drugs and metabolic syndrome-targeting therapies. While preliminary clinical results are encouraging, further research is required to ensure their efficacy, safety, and viability.

3.5 Autoimmune and Inflammatory Diseases

Targeted delivery of drugs has been successful in treating autoimmune and chronic inflammatory disorders through the selective manipulation of the immune system without causing any suppression of the immune system. The targeted delivery of drugs like corticosteroids, biologic therapy, monoclonal antibodies, DMARDS, and anti-inflammatory drugs for ailments like rheumatoid arthritis, inflammatory bowel disorder, psoriasis, lupus erythematosus, and multiple sclerosis has been studied clinically in humans[24].

The delivery of drugs with nanoparticles and targeting ligands has shown increased localization of drugs in inflamed tissues, improved efficacy of therapy, lower toxicity of treatment, and greater disease management. In addition, there is clinical data which shows that biologically targeted drug delivery will decrease the need for frequent drug administration and increase the compliance of treatment. However, the variable immune response and resistance remain important clinical problems.

3.6 Infectious Diseases and Vaccines

Targeted drug delivery has been pivotal in helping enhance the prevention and treatment of infectious diseases through improved antimicrobial delivery and vaccines. There are studies conducted on humans that have tested various targeted drug delivery methods for infectious diseases, such as COVID-19, flu, hepatitis, tuberculosis, HIV infection, and bacterial diseases[25].

Lipid nanoparticles for mRNA vaccines have proven to be highly successful in clinical applications due to their excellent delivery capabilities, potent immunogenic response, and high protection efficacy in humans on a mass scale. Antimicrobials delivered using targeting mechanisms have also increased the efficacy of therapy by increasing the concentration of drugs at the infection site, decreasing resistance, and lowering the toxicity of the treatment. However, despite all these advancements, there are still some barriers that need to be addressed in the future.

4. CHALLENGES, CLINICAL TRANSLATION, AND FUTURE PERSPECTIVES

Even with tremendous progress made in the development of targeted drug delivery systems, there are various issues which still remain to be addressed in order to make the system applicable in human healthcare. Some of the biggest problems include the presence of physiological barriers that hinder the efficiency of the targeted drug delivery systems[26]. These barriers include fast clearance of the agents through the mononuclear phagocyte system, poor penetration of the drug into solid tumors, heterogeneous distribution of receptors and physiological barriers such as the blood-brain barrier. In addition, variations in the progression of diseases among different patients and the response of the body to drugs have made the process of developing the therapy inconsistent.

Another crucial challenge relates to the safety and biocompatibility of such drug delivery technologies over time, as well as their regulation. Despite the positive results that have been achieved through the use of formulations based on nanoparticles, there is some concern about the possible adverse impact of nanoparticles on the body – namely, about nanoparticle toxicity, immunogenicity, biodistribution over time, and potential accumulation in healthy organs after repeated application[27]. Besides, discrepancies between regulatory frameworks of different countries, lack of standard methods of nanoparticles characterization, and necessity of conducting comprehensive safety trials can slow down the introduction of new targeted drugs into use. Manufacturing of targeted drugs and further commercialization is another difficult issue since it is associated with high costs of production, which should be controlled, and with GMP compliance.

The application of AI, machine learning, and precision medicine is a promising strategy that can help overcome the above-discussed problems and pave the way for novel next-generation target-specific drug delivery systems. In this regard, AI-enabled modeling techniques can enhance the optimization of carrier properties, assess the nature of interaction between the drug and carrier, select proper molecular targets, and enable better stratification of patients based on clinical and genetic information[28]. Furthermore, in combination with advanced imaging techniques and guided biomarker therapy and therapeutic monitoring, the implementation of these techniques may lead to the development of personalized strategies with enhanced efficacy and fewer side effects.

The future direction of medicinal chemistry research should involve efforts aimed at designing multifunctional, biodegradable nanocarriers that exhibit high specificity, targeted drug delivery,

and good safety profiles in long-term studies. It is also important to shift research focus toward the organization and implementation of multicenter clinical trials in humans, development of production and regulatory guidelines, and use of novel technologies such as gene editing, RNA delivery systems, exosome-based delivery vehicles, biomimetic nanoparticles, and smart drug delivery systems[29]. Such innovations can help solve existing problems in targeted drug delivery and enable its practical application in medicine.

Table 1: Summary of Selected Literature on Targeted Drug Delivery Systems[30]

Author(s) & Year	Study Focus	Methodology/Model	Key Findings
Kalaydina et al. (2018)[31]	Smart drug delivery for cancer	Review	Smart nanocarriers improved targeted drug release and therapeutic efficacy but faced clinical translation challenges.
Hu et al. (2018)[32]	DNA nanotechnology for drug delivery	Review	DNA nanostructures enhanced targeted delivery and controlled drug release; stability and manufacturing remained challenges.
Vargason et al. (2021)[33]	Commercial drug delivery technologies	Review	Commercial delivery systems improved treatment outcomes; scalability and regulatory approval were key barriers.
Visan & Negut (2024)[34]	AI in drug discovery and delivery	Review	Artificial intelligence optimized drug design and personalized delivery but required further validation and regulatory support.
Duan et al. (2020)[35]	Solid lipid nanoparticles (SLNs)	Review	SLNs improved bioavailability and controlled drug release; formulation stability and manufacturing required further improvement.

5. DISCUSSION

This review compiles the findings of recent clinical studies performed on human subjects involving targeted drug delivery systems, and then goes on to analyze their significance to contemporary medicinal chemistry. The review discusses the current progress in the field, and its implications as well as the gaps in knowledge at present and in the future[36].

5.1 Interpretation and Analysis of Findings

The results of this review suggest that targeted drug delivery systems have led to a great improvement in treating a number of human diseases due to their higher efficacy, increased drug targeting specificity, and reduced toxicity to the body system. It is proven by human clinical trials that liposomes, polymeric nanoparticles, antibody-drug conjugates (ADCs), and ligand-targeting systems show better pharmacokinetic properties, drug release control, and clinical outcomes than conventional drug delivery systems[37]. Of these systems, liposomal systems and ADCs exhibit the highest success rates clinically, especially in treating cancers.

5.2 Clinical Implications and Significance

The increasing clinical use of targeted drug delivery technology has led to increased accuracy and personalization of treatment approaches in the fields of oncology, cardiovascular disease, neurology, diabetes, autoimmune disorders, and infectious diseases[38]. In addition to reducing the side effects of these treatments and enhancing their efficacy and safety, these drug delivery technologies have improved the quality of care for patients. Moreover, recent innovations in nanotechnology, biomarkers, and artificial intelligence are expected to help in making clinical decisions and precision medicine possible[39].

5.3 Research Gaps and Future Research Directions

In spite of considerable advancements, there still exist a number of issues that include lack of long-term human safety data, biological barriers, expensive manufacturing, and many others. Clinical data is predominantly related to oncology, but there is a need for additional human-based studies in other fields[40]. Further investigations should be conducted regarding large-scale multicenter clinical trials, proper manufacturing process, efficient formulations, and use of new technologies like artificial intelligence, gene therapy, RNA-based drugs, and intelligent nanocarriers to improve the clinical translation and broader application of targeted drug delivery systems.

6. CONCLUSION

This review highlights that targeted drug delivery systems constitute one of the most important breakthroughs in the field of medicinal chemistry, because it allows the delivery of therapeutic agents in a selective manner to the sites of diseases, thus increasing the effectiveness of the therapy and also the drug bioavailability, while reducing the toxic effects of drugs. Clinical human evidence has demonstrated that the delivery platforms that are developed today, such as liposomes,

polymeric nanoparticles, antibody–drug conjugates (ADCs), ligand-targeted delivery systems and intelligent nanocarriers, have improved clinical results in various types of diseases, such as cancer, cardiovascular diseases, neurological disorders, diabetes, autoimmune diseases and infectious diseases. Such technologies help in the development of controlled drug release, improved pharmacokinetic behavior, increased treatment precision, and better safety profiles, which are considered to be an important part of the precision medicine. Yet, however much success they have had in their application, some of the obstacles include biological and physiological barriers, safety issues, difficulties in manufacture and production costs, regulatory issues, and lack of large scale clinical testing. It is therefore concluded from this review that advances in nanotechnology, artificial intelligence, biomarker-guided treatment approaches, genetic/RNA-based therapies and intelligent responsive drug delivery systems may help in achieving better targeting and results in treatment. Future interdisciplinary cooperation and large-scale human trials are critical for the resolution of current limitations and successful transfer of next-generation targeted drug delivery systems to clinical use.

REFERENCES

1. Tewabe, A., Abate, A., Tamrie, M., Seyfu, A., & Abdela Siraj, E. (2021). Targeted drug delivery—from magic bullet to nanomedicine: principles, challenges, and future perspectives. Journal of Multidisciplinary Healthcare, 1711-1724.
2. Gao, J., Karp, J. M., Langer, R., & Joshi, N. (2023). The future of drug delivery. Chemistry of Materials, 35(2), 359-363.\
3. Ezike, T. C., Okpala, U. S., Onoja, U. L., Nwike, C. P., Ezeako, E. C., Okpara, O. J., ... & Nwanguma, B. C. (2023). Advances in drug delivery systems, challenges and future directions. Heliyon, 9(6).
4. Chen, W., Sun, Z., & Lu, L. (2021). Targeted engineering of medicinal chemistry for cancer therapy: recent advances and perspectives. Angewandte Chemie International Edition, 60(11), 5626-5643.
5. Ismail, Y., & Kishore, S. (2025). Recent advances in targeted drug delivery systems. Journal of Pharma Insights and Research, 3(2), 031-042.
6. Manzari, M. T., Shamay, Y., Kiguchi, H., Rosen, N., Scaltriti, M., & Heller, D. A. (2021). Targeted drug delivery strategies for precision medicines. Nature Reviews Materials, 6(4), 351-370.
7. Jain, K. K. (2019). An overview of drug delivery systems. Drug delivery systems, 1-54.
8. Rahimi, H., Davaran, S., Nosrati, H., & Danafar, H. (2021). Targeted drug delivery: advancements, applications, and challenges. Modeling and Control of Drug Delivery Systems, 195-212.

9. Yadav, S., Palei, N. N., Dinda, S. C., & Dhar, A. K. (2024). Drug delivery in biotechnology: present and future. Concepts in pharmaceutical biotechnology and drug development, 103-138.
10. Cheng, X., Xie, Q., & Sun, Y. (2023). Advances in nanomaterial-based targeted drug delivery systems. Frontiers in bioengineering and biotechnology, 11, 1177151.
11. Lou, J., Duan, H., Qin, Q., Teng, Z., Gan, F., Zhou, X., & Zhou, X. (2023). Advances in oral drug delivery systems: challenges and opportunities. Pharmaceutics, 15(2), 484.
12. Patra, J. K., Das, G., Fraceto, L. F., Campos, E. V. R., Rodriguez-Torres, M. D. P., Acosta-Torres, L. S., ... & Shin, H. S. (2018). Nano based drug delivery systems: recent developments and future prospects. Journal of nanobiotechnology, 16(1), 71.
13. Homayun, B., Lin, X., & Choi, H. J. (2019). Challenges and recent progress in oral drug delivery systems for biopharmaceuticals. Pharmaceutics, 11(3), 129.
14. Chandrakala, V., Aruna, V., & Angajala, G. (2022). Review on metal nanoparticles as nanocarriers: current challenges and perspectives in drug delivery systems. Emergent Materials, 5(6), 1593-1615.
15. Singh, A. P., Biswas, A., Shukla, A., & Maiti, P. (2019). Targeted therapy in chronic diseases using nanomaterial-based drug delivery vehicles. Signal transduction and targeted therapy, 4(1), 33.
16. Reddy, K. T. K., & Reddy, A. S. (2025). Recent breakthroughs in drug delivery systems for targeted cancer therapy: an overview. Cellular, Molecular and Biomedical Reports, 5(1), 13-27.
17. Elmowafy, M., Shalaby, K., Elkomy, M. H., Alsaidan, O. A., Gomaa, H. A., Abdelgawad, M. A., & Mostafa, E. M. (2023). Polymeric nanoparticles for delivery of natural bioactive agents: recent advances and challenges. Polymers, 15(5), 1123.
18. Sung, Y. K., & Kim, S. W. (2020). Recent advances in polymeric drug delivery systems. Biomaterials Research, 24(1), 12.
19. Rosenblum, D., Joshi, N., Tao, W., Karp, J. M., & Peer, D. (2018). Progress and challenges towards targeted delivery of cancer therapeutics. Nature communications, 9(1), 1410.
20. Lee, S. H., Bajracharya, R., Min, J. Y., Han, J. W., Park, B. J., & Han, H. K. (2020). Strategic approaches for colon targeted drug delivery: an overview of recent advancements. Pharmaceutics, 12(1), 68.
21. Gupta, T. K., Budarapu, P. R., Chappidi, S. R., YB, S. S., Paggi, M., & Bordas, S. P. (2019). Advances in carbon based nanomaterials for bio-medical applications. Current Medicinal Chemistry, 26(38), 6851-6877.
22. Khan, M. I., Hossain, M. I., Hossain, M. K., Rubel, M. H. K., Hossain, K. M., Mahfuz, A. M. U. B., & Anik, M. I. (2022). Recent progress in nanostructured smart drug delivery systems for cancer therapy: a review. ACS applied bio materials, 5(3), 971-1012.

23. Wang, J., Li, B., Qiu, L., Qiao, X., & Yang, H. (2022). Dendrimer-based drug delivery systems: History, challenges, and latest developments. Journal of biological engineering, 16(1), 18.
24. Adepu, S., & Ramakrishna, S. (2021). Controlled drug delivery systems: current status and future directions. Molecules, 26(19), 5905.
25. Avcil, M., & Çelik, A. (2021). Microneedles in drug delivery: progress and challenges. Micromachines, 12(11), 1321.
26. Gavas, S., Quazi, S., & Karpiński, T. M. (2021). Nanoparticles for cancer therapy: current progress and challenges. Nanoscale research letters, 16(1), 173.
27. Patrick, G. L. (2023). An introduction to medicinal chemistry. Oxford university press.
28. Narayanaswamy, R., & Torchilin, V. P. (2019). Hydrogels and their applications in targeted drug delivery. Molecules, 24(3).
29. Afzal, O., Altamimi, A. S., Nadeem, M. S., Alzarea, S. I., Almalki, W. H., Tariq, A., ... & Kazmi, I. (2022). Nanoparticles in drug delivery: from history to therapeutic applications. Nanomaterials, 12(24), 4494.
30. Yusuf, A., Almotairy, A. R. Z., Henidi, H., Alshehri, O. Y., & Aldughaim, M. S. (2023). Nanoparticles as drug delivery systems: a review of the implication of nanoparticles' physicochemical properties on responses in biological systems. Polymers, 15(7), 1596.
31. Kalaydina, R. V., Bajwa, K., Qorri, B., Decarlo, A., & Szewczuk, M. R. (2018). Recent advances in "smart" delivery systems for extended drug release in cancer therapy. International journal of nanomedicine, 4727-4745.
32. Hu, Q., Li, H., Wang, L., Gu, H., & Fan, C. (2018). DNA nanotechnology-enabled drug delivery systems. Chemical reviews, 119(10), 6459-6506.
33. Vargason, A. M., Anselmo, A. C., & Mitragotri, S. (2021). The evolution of commercial drug delivery technologies. Nature biomedical engineering, 5(9), 951-967.
34. Visan, A. I., & Negut, I. (2024). Integrating artificial intelligence for drug discovery in the context of revolutionizing drug delivery. Life, 14(2), 233.
35. Duan, Y., Dhar, A., Patel, C., Khimani, M., Neogi, S., Sharma, P., ... & Vekariya, R. L. (2020). A brief review on solid lipid nanoparticles: Part and parcel of contemporary drug delivery systems. RSC advances, 10(45), 26777-26791.
36. Fenton, O. S., Olafson, K. N., Pillai, P. S., Mitchell, M. J., & Langer, R. (2018). Advances in biomaterials for drug delivery. Advanced Materials, 30(29), 1705328.
37. Bostrom, J., Brown, D. G., Young, R. J., & Keseru, G. M. (2018). Expanding the medicinal chemistry synthetic toolbox. Nature Reviews Drug Discovery, 17(10), 709-728.
38. Chu, D., Dong, X., Shi, X., Zhang, C., & Wang, Z. (2018). Neutrophil-based drug delivery systems. Advanced materials, 30(22), 1706245.

39. Alshawwa, S. Z., Kassem, A. A., Farid, R. M., Mostafa, S. K., & Labib, G. S. (2022). Nanocarrier drug delivery systems: characterization, limitations, future perspectives and implementation of artificial intelligence. Pharmaceutics, 14(4), 883.

40. Dadwal, A., Baldi, A., & Kumar Narang, R. (2018). Nanoparticles as carriers for drug delivery in cancer. Artificial cells, nanomedicine, and biotechnology, 46(sup2), 295-305.