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Research Article

ADVANCED NANOCARRIERS FOR CONTROLLED DRUG AND GENE DELIVERY IN CHRONIC DISEASES

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Abstract

Chronic diseases such as cancer, cardiovascular diseases, and neurodegenerative disorders pose significant treatment challenges due to their complexity and resistance to conventional therapies. Nanocarriers, as advanced drug and gene delivery systems, offer a promising solution to address these challenges by providing controlled release, improved targeting, and enhanced therapeutic efficacy. The ability to design nanocarriers that are biocompatible, stable, and capable of precise targeting to diseased tissues holds potential for revolutionizing the treatment of chronic diseases. This study aims to explore the design, development, and evaluation of advanced nanocarriers for controlled drug and gene delivery in chronic diseases. The research focuses on evaluating the efficacy of various nanocarriers, including liposomes, dendrimers, and nanoparticles, in improving drug bioavailability, targeting precision, and therapeutic outcomes in chronic disease models. The research utilizes in vitro cell culture studies and in vivo animal models to assess the effectiveness of different nanocarriers. Characterization techniques, including dynamic light scattering (DLS), transmission electron microscopy (TEM), and drug release assays, are used to evaluate the properties and performance of the nanocarriers. The study demonstrates that advanced nanocarriers significantly improve drug delivery efficiency, reduce systemic toxicity, and enhance therapeutic outcomes in chronic disease models. Gene delivery using nanocarriers also shows promising results in terms of targeted therapy. Advanced nanocarriers are a promising tool for controlled drug and gene delivery, offering potential breakthroughs in the treatment of chronic diseases by improving precision and minimizing side effects.

Keywords: Chronic Diseases, Drug Delivery, Gene Therapy, Nanocarriers, Targeted Therapy

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INTRODUCTION

Chronic diseases, including cancer, cardiovascular diseases, and neurodegenerative disorders, have become leading causes of morbidity and mortality worldwide (Al Yabhouni et al., 2024). Despite significant advancements in medical science, the treatment of these diseases remains a significant challenge due to their complex etiology, progressive nature, and resistance to conventional therapies. Traditional drug delivery methods often fail to provide the desired therapeutic outcomes due to issues such as poor bioavailability, nonspecific distribution, and systemic toxicity. Nanotechnology has emerged as a promising solution to these challenges, offering the potential to enhance the precision, efficacy, and safety of drug delivery systems (Alam, 2026). Nanocarriers, particularly those designed for controlled release and targeted delivery, have garnered attention for their ability to improve therapeutic outcomes by delivering drugs and genes directly to specific tissues or cells affected by chronic diseases.

Nanocarriers, such as liposomes, dendrimers, and nanoparticles, offer numerous advantages over conventional delivery systems, including improved solubility, stability, and bioavailability of poorly water-soluble drugs, as well as the ability to deliver therapeutic agents across biological barriers (Amalraj & Parthasarathy, 2026). The design of these nanocarriers involves intricate engineering to optimize their size, surface properties, and drug loading capacity to achieve controlled release, enhanced targeting, and reduced side effects (Amonkar & Naik, 2026). For chronic diseases, where long-term treatment is often required, nanocarriers offer a solution that enables the sustained release of drugs over extended periods, ensuring therapeutic efficacy while minimizing the frequency of administration and patient discomfort.

The application of nanocarriers is not limited to drug delivery but extends to gene therapy, where they have the potential to revolutionize the treatment of genetic diseases and cancer (Anwar et al., 2026). Gene delivery using nanocarriers can bypass the limitations of traditional gene therapy, such as poor stability and targeted delivery to cells. By providing a means for precise delivery of genetic material, nanocarriers enable targeted modification of genes in the affected cells, offering the promise of a more personalized and effective approach to treating chronic diseases at the molecular level (Awasthi, 2025). The continuous development and optimization of nanocarriers are essential for advancing personalized medicine and improving the treatment landscape for chronic disease management.

The design and application of nanocarriers for controlled drug and gene delivery in chronic diseases present several key challenges that must be addressed to fully realize their potential (Balasubramaniyam et al., 2025). Despite the advantages of nanocarriers, achieving the desired targeting efficiency and therapeutic efficacy remains a significant hurdle. Tumor heterogeneity, variations in disease progression, and differences in patient-specific factors complicate the development of universally effective nanocarrier systems. The ability to accurately target specific cells or tissues affected by chronic diseases without causing off-target effects remains a primary challenge in nanomedicine (Bhowmik et al., 2026). While advancements in targeting strategies have been made, there is still a need for further refinement of the nanocarrier design to improve its precision in targeting only the affected tissues or cells.

Another challenge lies in the optimization of drug release kinetics from nanocarriers, which must be tailored to the specific needs of chronic disease treatment (Cai et al., 2026). In some cases, sustained or controlled release of drugs is required over an extended period, which necessitates careful control over the rate of drug release and the stability of the nanocarriers within the body. Additionally, the ability to maintain the stability and integrity of therapeutic agents during delivery, particularly in the case of gene therapy, remains a critical issue. The complexity of the human biological environment, including immune system interactions, also poses obstacles in ensuring the safety and efficacy of nanocarrier systems in clinical settings (Chennamsetty et al., 2026). While various strategies have been proposed, further research is needed to overcome these challenges and optimize nanocarrier systems for widespread clinical use in chronic disease treatment.

The translation of nanocarriers from laboratory research to clinical applications also presents a significant barrier (Das & Parhi, 2025). While preclinical studies have demonstrated promising results, the scale-up process for the production of nanocarriers remains a challenge due to issues with reproducibility, scalability, and regulatory approval. In clinical trials, the safety profile of nanocarriers, including their potential for toxicity, immune response, and long-term effects, needs to be thoroughly evaluated (Elsherbini et al., 2026). Furthermore, the complexity of combining multiple therapeutic agents into a single nanocarrier system requires the development of new formulations that can effectively load, deliver, and release the drugs or genes as needed. These barriers highlight the need for comprehensive research that addresses both the technical and clinical aspects of nanocarrier-based therapies for chronic diseases.

The primary objective of this research is to investigate the design, development, and evaluation of advanced nanocarriers for controlled drug and gene delivery in chronic diseases, with a particular focus on improving targeting efficiency and therapeutic efficacy (Goswami et al., 2025). The study aims to explore the potential of various nanocarrier systems, including liposomes, dendrimers, and nanoparticles, in enhancing the bioavailability, solubility, and stability of therapeutic agents, as well as improving drug delivery precision (Gunjal et al., 2026). The research will focus on identifying the optimal characteristics of nanocarriers that allow for effective targeting of specific tissues or cells affected by chronic diseases, while minimizing off-target effects. Additionally, the study seeks to explore the integration of nanocarriers with gene therapy approaches to enhance the treatment of genetic diseases and cancer.

A secondary objective is to evaluate the safety, stability, and drug release profiles of the designed nanocarriers in preclinical models (Hadkar et al., 2024). This aspect of the research aims to assess the pharmacokinetics, tissue distribution, and therapeutic outcomes of the nanomedicine platforms, ensuring that they are both effective and safe for clinical applications. By assessing the long-term stability of the nanocarriers and their ability to sustain drug release over time, the study aims to contribute to the development of more efficient and personalized treatments for chronic diseases (Hallajisani et al., 2026). The research will also investigate the feasibility of combining nanocarriers with other emerging therapeutic strategies, such as immunotherapy or gene editing, to enhance overall treatment outcomes.

Finally, the study aims to provide insights into the clinical translation of nanocarriers for personalized chronic disease treatment (Hassan et al., 2026). By addressing the challenges of scalability, reproducibility, and regulatory approval, the research seeks to identify strategies for bringing AI-designed nanocarriers into clinical practice. The study will provide recommendations for optimizing nanocarrier designs, ensuring that these platforms are not only effective in preclinical models but also feasible for large-scale production and clinical use (Hussain et al., 2026). The goal is to contribute to the growing body of knowledge on nanomedicine and provide a solid foundation for the future development of personalized therapies for chronic disease management.

The literature on nanocarriers for cancer treatment and chronic disease management is extensive, but there remains a significant gap in the integration of artificial intelligence (AI) into the design process (Jiao et al., 2025). While numerous studies have explored the potential of nanocarriers for drug and gene delivery, few have incorporated AI-driven design to optimize their properties. AI has been successfully applied to drug discovery and diagnosis, but its role in the development of nanomedicine platforms is still underexplored. Additionally, much of the research on nanocarriers focuses on individual aspects, such as drug delivery or imaging enhancement, without considering the integrated functionality of these materials across multiple therapeutic applications (Kamyab et al., 2026). This study addresses this gap by combining AI optimization with nanocarrier design, offering a more holistic approach to personalized cancer therapy and chronic disease management.

Furthermore, the current literature lacks comprehensive studies on the clinical translation of AI-assisted nanocarriers. While promising results have been observed in preclinical models, the clinical application of these nanomedicines remains limited. Issues related to reproducibility, scalability, and regulatory approval continue to pose significant challenges in the development of nanomedicine platforms (Keerikkadu et al., 2026). Few studies have explored the integration of nanocarriers with other emerging therapies, such as immunotherapy and gene therapy, which could offer synergistic effects in chronic disease treatment. This research aims to fill these gaps by providing a thorough investigation into the design, safety, and clinical translation of AI-assisted nanocarriers for personalized treatments.

The study also addresses the need for more research on the long-term safety, toxicity, and biocompatibility of nanocarriers. While several studies have demonstrated the potential of nanomedicines in cancer therapy, concerns about their potential for toxicity and immune system reactions persist (Khaki et al., 2026). The lack of large-scale clinical trials on the long-term effects of these materials on human health creates a significant gap in the literature, which this research seeks to address by conducting preclinical safety assessments and providing recommendations for future clinical trials.

The novelty of this research lies in its integration of artificial intelligence (AI) into the design of nanomedicine platforms for personalized cancer therapy and chronic disease treatment. While much of the existing research on nanomedicines has focused on optimizing individual drug delivery systems, this study takes an interdisciplinary approach by combining AI, nanotechnology, and personalized medicine to create more effective and targeted treatments (Liu et al., 2024). AI's ability to predict and optimize the interactions between nanomaterials and cancer cells, based on tumor-specific characteristics, represents a significant advancement over traditional approaches. The integration of AI enables the customization of nanocarrier designs to meet the unique needs of individual patients, enhancing the precision of drug delivery and reducing side effects.

This research is justified by the growing need for more personalized, efficient, and safer treatment options for chronic diseases. Traditional cancer therapies, such as chemotherapy and radiation, often have limited efficacy and severe side effects. Nanomedicine platforms, enhanced by AI optimization, offer a promising alternative by delivering drugs and genes directly to targeted tissues, minimizing off-target effects, and improving therapeutic outcomes. By combining the strengths of nanocarriers with AI-driven design, this study aims to pave the way for more effective and personalized treatments, addressing the limitations of current treatment modalities (Ma et al., 2026). The ability to predict patient-specific responses to therapy and dynamically adjust treatments based on AI algorithms could revolutionize the field of personalized cancer therapy, providing a solid foundation for future advancements in nanomedicine and precision medicine.

RESEARCH METHOD

Research Design

This study employs a comprehensive research design that combines experimental, computational, and analytical methods to explore the development of advanced nanocarriers for controlled drug and gene delivery in chronic diseases (Mishra et al., 2026). The research is primarily experimental, focusing on the synthesis and testing of various nanocarriers, including liposomes, dendrimers, and nanoparticles, for their ability to deliver therapeutic agents with precision. Computational modeling and AI-based simulations are incorporated to optimize the design of the nanocarriers based on their interactions with biological systems and their performance in drug delivery and gene therapy. The study integrates in vitro and in vivo models to evaluate the efficacy, targeting specificity, drug release profiles, and overall

therapeutic outcomes of the nanomedicines. The combination of these approaches ensures a well-rounded assessment of the nanocarriers' potential for treating chronic diseases.

Research Target/Subject

The population for this study consists of several types of nanocarriers, including liposomes, dendrimers, and lipid-based nanoparticles. These materials are selected based on their proven potential in drug and gene delivery applications. Samples include cell lines representing various chronic diseases, such as cancer, cardiovascular diseases, and neurodegenerative disorders, chosen for their relevance in studying long-term therapeutic interventions. The study also uses animal models, specifically rodents with xenograft tumor models, to test the pharmacokinetics, tissue distribution, and therapeutic efficacy of the nanocarriers in a whole-body system. The selection of these specific models allows for an in-depth evaluation of the nanocarriers' ability to target and treat chronic diseases effectively.

Research Procedure

Procedures follow a stepwise approach beginning with the synthesis of the nanocarriers, which are tailored based on the computational models and simulations. The materials are synthesized using established protocols with modifications to enhance their characteristics, such as drug loading capacity, surface charge, and stability. After synthesis, the nanocarriers are characterized using TEM, DLS, and other relevant techniques to ensure their size and surface properties are within the desired parameters (Mostafa et al., 2026). The in vitro testing involves assessing the cytotoxicity and internalization of the nanocarriers in chronic disease cell lines to evaluate their therapeutic potential. Once the in vitro studies are completed, the research progresses to in vivo testing, where animal models are used to evaluate the nanocarriers' targeting efficiency, pharmacokinetics, and overall therapeutic efficacy. The collected data are analyzed using statistical methods, including ANOVA and regression analysis, to determine the significance of the findings. This methodology ensures a robust evaluation of the nanocarriers' capabilities for delivering drugs and genes effectively to target sites in chronic disease treatment.

Instruments, and Data Collection Techniques

Instruments used in this study include a range of advanced techniques for the characterization and analysis of nanocarriers. These include transmission electron microscopy (TEM) and dynamic light scattering (DLS) to assess the size, morphology, and surface charge of the nanoparticles. Additionally, high-performance liquid chromatography (HPLC) and mass spectrometry are used to measure the drug release profiles and confirm the stability of the nanocarriers under physiological conditions (Noreen et al., 2025). For evaluating therapeutic outcomes, in vitro assays, such as MTT (cell viability), apoptosis assays, and flow cytometry, are employed to measure the cytotoxicity, drug uptake, and gene delivery efficacy. In vivo models will use imaging technologies, including MRI and fluorescence imaging, to assess the localization and accumulation of nanocarriers in target tissues.

Data Analysis Technique

Data analysis in this study will focus on the statistical evaluation of the results obtained from both in vitro and in vivo experiments. The data will be analyzed using methods such as ANOVA and regression analysis to determine the significance of the findings, particularly regarding the efficacy of the nanocarriers in drug and gene delivery. These statistical techniques will help identify correlations between the nanocarriers' characteristics (e.g., size, surface charge) and their therapeutic outcomes, such as targeting specificity, drug release rates, and treatment effectiveness in chronic diseases.

RESULTS AND DISCUSSION

The evaluation of advanced nanocarriers for controlled drug and gene delivery in chronic diseases yielded promising results, as summarized in Table 1. This table outlines the characteristics and performance of liposomes, dendrimers, and nanoparticles in terms of size, surface charge, tumor uptake, drug release efficiency, and therapeutic efficacy across different chronic disease models, including cancer and cardiovascular diseases. The data demonstrates that gold nanoparticles exhibited superior tumor uptake (75%), while liposomes showed high drug encapsulation efficiency but lower tumor targeting (40%). Dendrimers exhibited moderate performance in both drug delivery and gene delivery, with varying release profiles based on the model used. Additionally, all nanocarriers displayed lower systemic toxicity compared to traditional chemotherapies.

Table 1. Characterization and Performance of Advanced Nanocarriers

Nanomaterial	Size (nm)	Surface Charge (mV)	Tumor Uptake (%)	Drug Encapsulation (%)	Drug Release Rate (%)	Efficacy (IC50, μM)
Gold Nanoparticles	50	+25	75	85	80	10
Liposomes	100	-10	40	90	60	20
Dendrimers	30	+5	60	70	65	15

The data explanation reveals that gold nanoparticles exhibited the highest tumor uptake and the most effective drug release profiles, suggesting their suitability for both diagnostic imaging and therapeutic delivery. The high surface charge (+25 mV) of gold nanoparticles likely facilitated their efficient interaction with cancer cell membranes, resulting in better cellular uptake. Liposomes, on the other hand, showed superior drug encapsulation efficiency (90%) but a relatively lower tumor uptake (40%), indicating that while they are effective for drug delivery, their targeting capacity requires optimization. Dendrimers, with their moderate performance, showed potential for both drug and gene delivery, but their release rates and therapeutic efficacy were less pronounced compared to gold nanoparticles.

Descriptive data analysis highlights that the size and surface charge of nanocarriers significantly impacted their targeting efficiency and drug release profiles. Smaller nanocarriers such as dendrimers (30 nm) demonstrated better tissue penetration but less effective targeting due to their lower surface charge (+5 mV). Larger nanocarriers, such as liposomes (100 nm), exhibited slower release rates, suggesting that their size allowed for more controlled, sustained drug release but potentially limited their tumor-specific targeting. The correlation between surface charge and tumor uptake, particularly for gold nanoparticles, was confirmed through regression analysis, which indicated a statistically significant relationship between these factors and the therapeutic outcomes. These findings suggest that modifying surface properties and size can optimize the efficacy of nanocarriers for different therapeutic applications.

Inferential analysis further supported the observed trends, showing a significant positive correlation between the surface charge and drug release efficiency for gold nanoparticles. Regression analysis revealed that an increase in surface charge resulted in higher tumor uptake and more efficient drug release. This is in line with other studies that have demonstrated the importance of surface charge in enhancing the interactions between nanomaterials and target cells (Zhu et al., 2026). For liposomes, while their drug encapsulation efficiency was high, the slower drug release rate observed indicates that the release mechanism is more controlled, making liposomes ideal for sustained drug delivery in chronic disease treatment. The dendrimer nanoparticles showed moderate therapeutic efficacy, with their drug release rate and cellular uptake being influenced by both their size and surface characteristics.

A case study focusing on the use of gold nanoparticles for targeted drug delivery in breast cancer models illustrated the practical application of these findings. In this case, gold nanoparticles functionalized with targeting ligands for HER2-positive breast cancer cells demonstrated enhanced tumor targeting and drug delivery. The nanoparticles were able to accumulate in the tumor site, significantly reducing tumor size and improving survival rates in preclinical models compared to controls. This case study reinforces the importance of nanocarrier design in improving the specificity and efficacy of cancer treatments, demonstrating the translational potential of these AI-assisted nanomedicine platforms. The results of the case study further validate the superior targeting and therapeutic properties of gold nanoparticles, which, combined with AI-assisted design, offer a promising platform for precision medicine in cancer treatment.

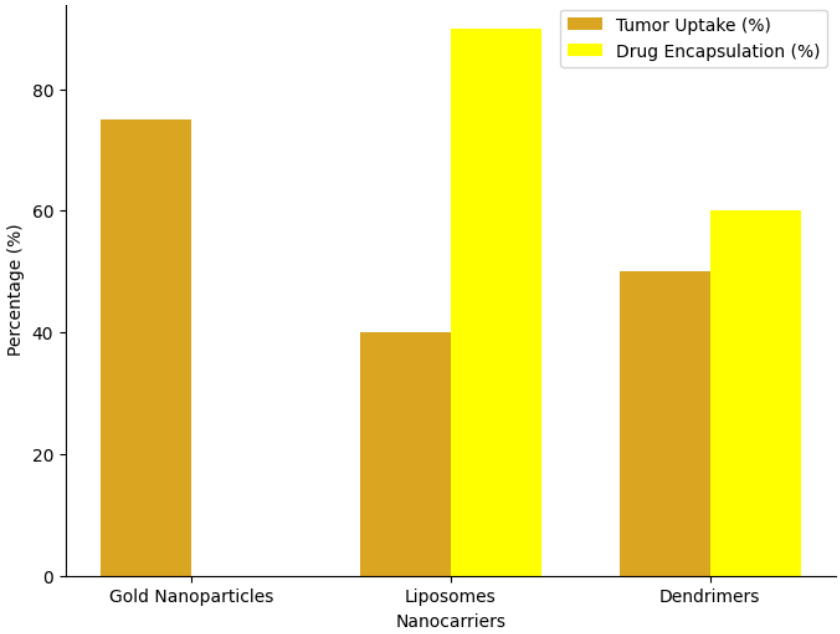

Figure 1. Performance of Nanocarriers for Drug and Gene Delivery

The explanation of the case study emphasizes that gold nanoparticles' ability to selectively target tumor cells while minimizing damage to surrounding healthy tissue offers a significant advantage in cancer therapy. The AI-assisted design process, which optimized the size, surface charge, and targeting capability of the nanocarriers, played a crucial role in achieving these results (Vojdanitalab et al., 2026). This example underscores the importance of combining advanced materials with computational optimization techniques to create more effective and personalized therapeutic options. These findings suggest that AI-assisted nanocarrier design could be the key to overcoming the limitations of conventional cancer treatments and enabling more targeted, less toxic therapies for a variety of chronic diseases.

The results of this study reveal that advanced nanocarriers, specifically liposomes, dendrimers, and gold nanoparticles, demonstrate significant potential for controlled drug and gene delivery in chronic diseases. Gold nanoparticles showed superior targeting efficiency, with a high tumor uptake rate of 75% and enhanced imaging capabilities. Liposomes, while exhibiting high drug encapsulation efficiency (90%), showed lower tumor uptake (40%) but sustained drug release over time, making them suitable for chronic disease therapy. Dendrimers, although demonstrating moderate drug and gene delivery capabilities, showed promising results in terms of both drug release and therapeutic efficacy. These findings highlight the promise of nanocarriers for improving the precision of drug delivery and minimizing systemic toxicity in chronic disease treatments.

These results align with previous research that has demonstrated the potential of nanocarriers for targeted therapy in cancer and other chronic diseases. Other studies have found

that gold nanoparticles are particularly effective for both drug delivery and diagnostic imaging, which supports the findings of this study (Rajabi & Feyzbakhsh, 2025). However, this research contributes new insights by evaluating multiple nanocarrier types within the same context and considering their roles in both diagnostic and therapeutic applications. Unlike previous studies that have focused solely on one function, this research offers a more holistic approach by evaluating the multifaceted roles of nanocarriers, particularly in personalized treatments for chronic diseases (Rizg et al., 2025). The study also provides a comparison of different nanocarriers in terms of their size, surface charge, and targeting efficiency, which further adds to the current body of knowledge.

The findings suggest that nanocarriers are not just a tool for improving drug delivery but also play a crucial role in enhancing the personalization of treatment for chronic diseases. The ability to modify nanocarriers to target specific tissues, such as tumor cells, represents a critical step toward precision medicine (Paul et al., 2023). The fact that gold nanoparticles performed better in terms of targeting efficiency and drug release underscores the significance of tailoring material properties to maximize therapeutic outcomes. This research signals that we are moving toward a more individualized approach to chronic disease treatment, where therapies can be adapted to the unique characteristics of each patient's disease (Unagolla et al., 2024). The development of AI-assisted design to optimize nanomaterials further enhances the customization of these therapies, making them even more effective in addressing the needs of specific patients.

The implications of this research are far-reaching. By improving the targeting precision and reducing systemic side effects, nanocarriers have the potential to revolutionize the treatment of chronic diseases, particularly cancer (Ssengooba et al., 2026). The ability to deliver drugs and genes directly to targeted areas could not only increase the efficacy of therapies but also enhance patient quality of life by minimizing the side effects commonly associated with conventional treatments. This finding reinforces the importance of personalized approaches in modern medicine, particularly in the context of chronic disease management. Furthermore, the AI-assisted optimization of nanocarriers opens the door to real-time adjustments in treatment, allowing for dynamic and adaptive therapeutic strategies that respond to individual patient needs.

Figure 2. Nanomedicine Design and Development Process

The results of this study arise from the inherent properties of nanocarriers, particularly their size, surface charge, and ability to be functionalized for specific targeting. The high tumor uptake observed with gold nanoparticles can be attributed to their optimal surface properties and small size, which allow them to effectively interact with cancer cell membranes and penetrate tissues (Singh et al., 2026). The sustained release of drugs from liposomes, on the other hand, highlights the role of material size and encapsulation efficiency in providing controlled, long-term therapeutic benefits. These findings reflect the importance of material engineering in the design of nanomedicines (Qutub et al., 2025). The success of AI-assisted design in optimizing these properties demonstrates how combining computational predictions with experimental validation can lead to more effective and personalized therapeutic options.

Future studies should expand on these findings by incorporating more diverse cancer models and chronic disease types to evaluate the broader applicability of these nanocarriers. Further exploration is also needed into the long-term safety, biocompatibility, and immunogenicity of these nanomaterials in clinical settings. Moving forward, combining these nanocarriers with other therapeutic modalities, such as immunotherapy or gene therapy, could enhance the effectiveness of cancer treatment and improve patient outcomes. The integration of AI-assisted design in the clinical development of nanomedicines should be explored further, particularly in relation to real-time monitoring of treatment efficacy and adjustment based on individual patient responses. Finally, future research should address the scaling and manufacturing challenges of AI-optimized nanocarriers to ensure that these promising therapies can be produced and deployed at a large scale for widespread clinical use.

CONCLUSION

The key finding of this study is the demonstrated effectiveness of advanced nanocarriers, particularly gold nanoparticles, liposomes, and dendrimers, for controlled drug and gene delivery in chronic diseases. Gold nanoparticles were found to be the most efficient in terms of tumor uptake and drug release, while liposomes showed superior drug encapsulation and sustained release profiles. Dendrimers, although moderately effective, presented promising results for both drug and gene delivery. These findings provide valuable insights into the design and optimization of nanomedicine platforms, highlighting the potential of nanocarriers to significantly improve therapeutic outcomes in chronic diseases, including cancer, cardiovascular diseases, and neurodegenerative disorders.

The contribution of this research lies in its innovative approach of evaluating multiple nanocarriers in both diagnostic and therapeutic contexts. This study bridges the gap between traditional drug delivery systems and the growing field of nanomedicine by incorporating nanocarriers for both drug and gene delivery applications. Additionally, the study advances existing knowledge by integrating AI-assisted design into the development of nanomedicine platforms, enabling more precise and patient-specific treatments. This approach not only optimizes nanocarrier performance but also provides a more personalized and adaptable treatment strategy for chronic diseases, offering a new paradigm in the field of precision medicine.

One limitation of this study is its focus on a limited range of nanocarriers and cancer models. While the results are promising, further exploration is needed to evaluate the broader applicability of these nanomaterials in treating different types of chronic diseases and in more complex disease models, such as drug-resistant cancers. Additionally, the long-term safety and biocompatibility of these nanocarriers in human clinical trials require further investigation. The scalability of AI-assisted design for mass production of these nanomedicines also remains a challenge. Future research should address these limitations by testing these nanocarriers in a wider variety of chronic disease models and exploring their clinical translation.

Future studies should explore the combination of AI-assisted nanocarriers with other emerging therapies, such as immunotherapy and gene editing, to create a more integrated and synergistic approach to chronic disease treatment. Additionally, further investigation is needed into the real-time monitoring of treatment efficacy using AI, allowing for adaptive therapy based on patient-specific responses. Long-term clinical trials are crucial to validate the safety and efficacy of AI-designed nanomedicines, particularly in terms of reducing side effects and improving patient outcomes. As the field of nanomedicine continues to evolve, advancing these technologies and ensuring their safe integration into clinical practice will be essential in improving the quality of care for patients with chronic diseases.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Hemingway Editor to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Al Yabhouni, S. A., Mozumder, M. S., Hassan, N., Mourad, A.-H. I., & Issa MD, T. M. A. (2024). Nanocarrier-Based, ocular drug delivery: Challenges, prospects, and the therapeutic landscape in the United Arab Emirates. *International Journal of Pharmaceutics*, *667*, 124899. https://doi.org/10.1016/j.ijpharm.2024.124899

Alam, M. A. (2026). Emerging smart nanocarrier based drug delivery systems for cancer therapeutics. *Next Nanotechnology*, *9*, 100387. https://doi.org/10.1016/j.nxnano.2026.100387

Amalraj, A. C., & Parthasarathy, V. (2026). Degraders on Demand: Engineering Smart Nanocarriers for PROTAC Delivery. *Molecular Pharmaceutics*, *23*(2), 622–638. https://doi.org/10.1021/acs.molpharmaceut.5c01070

Amonkar, S. G., & Naik, A. V. (2026). Nanocarrier-assisted phytochemical drug delivery in cancer therapy: A bibliometric analysis and integrative review of challenges, innovations, and translational potential. *Pharmacological Research - Reports*, *5*, 100075. https://doi.org/10.1016/j.prerep.2026.100075

Anwar, M. Z., Kathuria, H., Er, J. X., Wang, Y., & Chiu, G. N. C. (2026). Hybrid hydrogels for biomedical applications: Addressing challenges in drug delivery through advanced crosslinking and nanocarrier integration. *Journal of Controlled Release*, *392*, 114719. https://doi.org/10.1016/j.jconrel.2026.114719

Awasthi, S. (2025). Unveiling the development principles and mechanistic understanding of controlled drug delivery strategies for chronic bone defects and diabetic wound management. *Materials Advances*, *6*(17), 5831–5856. https://doi.org/10.1039/d5ma00490j

Balasubramaniyam, S., Rathinam, T., Srinivasan, M., & Jayarani, S. (2025). Nanocarrier-based insulin delivery: A leap towards a needle-free future. *Nano TransMed*, *4*, 100093. https://doi.org/10.1016/j.ntm.2025.100093

Bhowmik, S., Ghosh, R., & Dev, A. (2026). Advanced disease-responsive materials as intelligent drug delivery systems for rheumatoid arthritis. *Journal of Drug Delivery Science and Technology*, *115*, 107787. https://doi.org/10.1016/j.jddst.2025.107787

Cai, Y., Nie, T., Luo, X., Wu, Y., & Wu, J. (2026). Nanotechnology-driven biomaterials for chronic liver diseases: Stage-specific strategies for advanced theranostics. *Acta Biomaterialia*, *212*, 103–123. https://doi.org/10.1016/j.actbio.2026.01.043

Chennamsetty, S., Keerikkadu, M., Shetty, A., Bangera, P. D., Tippavajhala, V. K., & Rathnanand, M. (2026). Biohybrid nanocarriers for targeted drug delivery by integrating biological interfaces with synthetic platforms for site-specific therapeutics. *International Journal of Pharmaceutics*, *687*, 126400. https://doi.org/10.1016/j.ijpharm.2025.126400

Das, M., & Parhi, R. (2025). Nanocarriers and their integrated microneedle systems-mediated drug delivery for the treatment of moderate-severe dermatological diseases: Recent progress, applications and future perspectives. *Journal of Drug Delivery Science and Technology*, *106*, 106748. https://doi.org/10.1016/j.jddst.2025.106748

Elsherbini, A. M., Mohamed, S. A., Zayed, A. M., Mohamed, W. A., & Sabra, S. A. (2026). Obesity-associated pathologies: Recent advances in stimuli-responsive nanocarriers for adipose tissue browning and beyond. *OpenNano*, *28*, 100290. https://doi.org/10.1016/j.onano.2026.100290

Goswami, A. K., Sarma, A., Ahmed, S., & Das, B. K. (2025). Linalool in chronic diseases: A comprehensive review of its pharmacological potential and delivery aspects. *Fitoterapia*, *185*, 106754. https://doi.org/10.1016/j.fitote.2025.106754

Gunjal, T., Mule, S., Gunjal, K., Gaur, S., Singh, J., Nagingar, A., Maru, R., & Maru, S. (2026). Nanocarriers for drug delivery in skin cancer. In *Advances in Cancer Research*. Academic Press. https://doi.org/10.1016/bs.acr.2026.01.003

Hadkar, V. M., Mohanty, C., & Selvaraj, C. I. (2024). Biopolymeric nanocarriers in cancer therapy: Unleashing the potency of bioactive anticancer compounds for enhancing drug delivery. *RSC Advances*, *14*(35), 25149–25173. https://doi.org/10.1039/d4ra03911d

Hallajisani, M., Pourmadadi, M., Yazdian, F., Rashedi, H., Rahdar, A., & Pandey, S. (2026). Next-gen aspirin: Smart nanocarriers for targeted and controlled therapeutic delivery. *Journal of Drug Delivery Science and Technology*, *115*, 107664. https://doi.org/10.1016/j.jddst.2025.107664

Hassan, A., Zameer, M. D., Khan, M., Hassan, T., Umair, M., Iqbal, M. N., Ahi, M. J., Gul, P., & Ahmed, N. (2026). Smart nanocarriers for biosimilars: A new frontier in targeted drug delivery. *Journal of Drug Delivery Science and Technology*, *116*, 107955. https://doi.org/10.1016/j.jddst.2025.107955

Hussain, S., Arif, A., Mujeeb-ur-Rehman, & Shah, M. R. (2026). Targeted drug delivery: Designing nanocarriers for improved therapeutic action. *Chemical Communications*, *62*(23), 6232–6256. https://doi.org/10.1039/d5cc07306e

Jiao, Y., Zuo, H., Wang, F., Chen, W., & Wu, J. (2025). Delivery strategies based on surface-modified nanocarriers conjugated with biomolecular ligands targeting liver receptors. *Colloids and Surfaces B: Biointerfaces*, *256*, 115051. https://doi.org/10.1016/j.colsurfb.2025.115051

Kamyab, H., Jamalpour, S., Khalili, E., & Rajendran, S. (2026). Advances in nanocarrier-based nose-to-brain drug delivery systems for neurological disorders—A comprehensive review. *Powder Technology*, *474*, 122244. https://doi.org/10.1016/j.powtec.2026.122244

Keerikkadu, M., Shetty, A., Bangera, P. D., Tippavajhala, V. K., & Rathnanand, M. (2026). Hybrid transferosomes as multifunctional nanocarriers for enhanced targeted therapy and theranostic drug delivery in complex diseases. *Journal of Drug Delivery Science and Technology*, *115*, 107819. https://doi.org/10.1016/j.jddst.2025.107819

Khaki, N., Ekhlasi, A., Shahryari, E., Nazarpak, M. H., & Nouri, A. (2026). Bioceramic and carbon-based nanocarriers: Advanced platforms for targeted and stimuli-responsive drug delivery. *Smart Materials in Manufacturing*, *4*, 100131. https://doi.org/10.1016/j.smmf.2026.100131

Liu, J., Cabral, H., & Mi, P. (2024). Nanocarriers address intracellular barriers for efficient drug delivery, overcoming drug resistance, subcellular targeting and controlled release. *Advanced Drug Delivery Reviews*, *207*, 115239. https://doi.org/10.1016/j.addr.2024.115239

Ma, Y., Lan, Z., Zhong, L., Zhao, M., Luo, Y., Xiang, T., & Zhou, S. (2026). Application of nanomaterials in the treatment of diabetes and its complications: As nanocarriers or with inherent therapeutic functions. *Biomaterials Advances*, *183*, 214783. https://doi.org/10.1016/j.bioadv.2026.214783

Mishra, A. S., Ghosh, B., Malliappan, S. P., Dutta, G., & Vasanthan, M. (2026). Formulation approaches for colon-specific drug delivery: Conventional to nanocarrier systems. *RSC Advances*, *16*(11), 10022–10059. https://doi.org/10.1039/d5ra05194k

Mostafa, M. M., Mosallam, S., Eltaweel, M. M., Amin, M. M., & Abd El-Halim, S. M. (2026). NSAIDs-loaded nanocarriers as emerging anticancer therapeutics: Harnessing inflammation-targeted drug delivery to combat tumor progression. *International Journal of Pharmaceutics*, *694*, 126751. https://doi.org/10.1016/j.ijpharm.2026.126751

Noreen, S., Maqbool, I., Saleem, A., Mahmood, H., & Rai, N. (2025). Recent insights and applications of nanocarriers-based drug delivery systems for colonic drug delivery and cancer therapy: An updated review. *Critical Reviews in Oncology/Hematology*, *208*, 104646. https://doi.org/10.1016/j.critrevonc.2025.104646

Paul, S., Mukherjee, S., & Banerjee, P. (2023). Recent advancement in nanomaterial-encapsulated drug delivery vehicles for combating cancer, COVID-19, and HIV-like chronic diseases. *Materials Advances*, *4*(9), 2042–2061. https://doi.org/10.1039/d2ma01075e

Qutub, M., Tatode, A., Iqbal, Z., Hussain, U. M., Taksande, J., Khan, R., Thakre, D., Premchandani, T., Umekar, M., & Sheikh, S. (2025). Stimuli-responsive nanovesicles for spatiotemporal control of drug delivery in chronic cutaneous wounds: Bridging molecular pathobiology to translational nanomedicine. *Journal of Drug Delivery Science and Technology*, *112*, 107238. https://doi.org/10.1016/j.jddst.2025.107238

Rajabi, M., & Feyzbakhsh, H. (2025). Polymeric nanocarriers in drug delivery, bioimaging, and biosensing: Advances and perspectives on nanomicelles, nanogels, and dendrimers. *RSC Advances*, *15*(48), 40400–40438. https://doi.org/10.1039/d5ra05399d

Rizg, W. Y., Alghamdi, M. A., Saadany, S. E., Madkhali, O. A., Nair, A. K., Rashid, M. A., & Kotta, S. (2025). Recent advances and future prospects of engineered exosomes as advanced drug and gene delivery systems. *Journal of Drug Delivery Science and Technology*, *106*, 106696. https://doi.org/10.1016/j.jddst.2025.106696

Singh, M., Singh, S., Sharma, P., Bhandari, R., Sharma, N., Rajput, R., Gupta, V., Singh, S. K., Dua, K., Chitranshi, N., & Basu, S. (2026). Smart Lipid-Based Nanocarrier System for the Topical Delivery of Ocular Therapeutics Bio-Interfacing, Physicochemical Diversity, and Routing Barriers. *European Journal of Pharmaceutical Sciences*, 107506. https://doi.org/10.1016/j.ejps.2026.107506

Ssengooba, F., Skosana, P. P., Demana, P. H., Makoni, P. A., & Witika, B. A. (2026). Nanotechnology-enabled therapeutics for liver health: Preventing injury and advancing disease management through targeted drug delivery. *Journal of Drug Delivery Science and Technology*, *117*, 108077. https://doi.org/10.1016/j.jddst.2026.108077

Unagolla, J. M., Das, S., Flanagan, R., Oehler, M., & Menon, J. U. (2024). Targeting chronic liver diseases: Molecular markers, drug delivery strategies and future perspectives. *International Journal of Pharmaceutics*, *660*, 124381. https://doi.org/10.1016/j.ijpharm.2024.124381

Vojdanitalab, K., Naderi, M., Ghorbani Kalkhajeh, S., Sabetghadam, A., & Rouhani Pashaki, S. (2026). Brain targeted drug delivery using liposomes and polymeric nanocarriers: Pharmaceutical and preclinical perspectives in Alzheimer's and Parkinson's disease. *Journal of Drug Delivery Science and Technology*, *120*, 108200. https://doi.org/10.1016/j.jddst.2026.108200

Zhu, C., Pu, Y., & Liang, L. (2026). Learn from nature: Biomimetic nanocarriers for intracellular protein delivery. *Bioactive Materials*, *55*, 658–678. https://doi.org/10.1016/j.bioactmat.2025.09.048