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Smart Drug Delivery Systems: Integrating Nanotechnology, Personalized Medicine, and Theranostic Approaches for Enhanced Therapeutic Outcomes

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Abstract: Smart drug delivery systems represent a paradigm shift in pharmaceutical sciences, integrating advanced nanotechnology, personalized medicine approaches, and theranostic capabilities to achieve enhanced therapeutic outcomes with reduced side effects. This comprehensive review examines the current state and future prospects of intelligent drug delivery platforms that utilize responsive mechanisms, targeted delivery, and real-time monitoring capabilities. The global smart drug delivery systems market, valued at $12 billion in 2024, is projected to reach $48.3 billion by 2034, reflecting a compound annual growth rate of 17%. This growth is driven by the increasing prevalence of chronic diseases, which account for 74% of global deaths according to the World Health Organization, and the urgent need for more effective, personalized therapeutic interventions. The integration of nanotechnology platforms, including liposomes, polymeric nanoparticles, and protein-drug conjugates, with biomarker-guided targeting and theranostic imaging capabilities, offers unprecedented opportunities for precision medicine. Recent FDA approvals of 18 personalized medicines in 2024, representing 38% of all newly approved therapeutic entities, underscore the regulatory acceptance and clinical potential of these advanced delivery systems. This article provides a comprehensive analysis of current technologies, clinical applications, regulatory landscape, and future directions in smart drug delivery systems.

Keywords: *Smart drug delivery, nanotechnology, personalized medicine, theranostics, targeted therapy, biomarkers, precision medicine, nanomedicine*

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1. Introduction

The field of pharmaceutical drug delivery has been radically transformed by the development of smart drug delivery systems (SDDS), which combine nanotechnology, personalized medicine, and theranostic strategies (Boppana et al., 2024; Adepu & Ramakrishna, 2021). Conventional drug delivery techniques, which involve systemic administration and widespread distribution in the body, frequently lead to less effective therapeutic results due to low bioavailability, lack of specific targeting, and considerable side effects (Prabahar et al., 2021). Smart drug delivery systems overcome these basic challenges by using advanced materials, microelectronics, and responsive mechanisms to provide controlled, targeted, and adaptive drug delivery (Sanchez-Moreno et al., 2024).

Intelligent drug delivery systems go beyond traditional sustained-release methods by incorporating features that allow them to respond to physiological signals, target specific cell groups, and monitor treatment effectiveness in real-time (Boppana et al., 2024). These systems combine various

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functions such as drug encapsulation, targeted delivery, controlled release, and diagnostic imaging into one platform (Puccetti et al., 2024). The use of nanotechnology has significantly advanced this field, allowing for the creation of nanoparticle-based carriers that can bypass biological barriers, concentrate at disease locations using passive or active targeting strategies, and release their therapeutic contents in reaction to particular environmental triggers (Mitchell et al., 2021; Egwu et al., 2024).

The driving forces behind the rapid development of smart drug delivery systems include the increasing prevalence of chronic diseases, the growing emphasis on personalized medicine, and advances in nanotechnology and biomaterials science. Chronic diseases, including cardiovascular diseases, cancer, diabetes, and respiratory disorders, currently account for 74% of global deaths and are projected to represent 86% of the estimated 90 million deaths per year by 2050. This alarming trend necessitates the development of more effective therapeutic approaches that can provide targeted treatment with minimal side effects.

The global market for smart drug delivery systems has seen significant expansion, hitting $12 billion in 2024 and expected to grow at a compound annual rate of 17%, reaching $48.3 billion by 2034 (Global Market Insights, 2025). This growth is driven by advancements in wearable drug delivery technology, a growing demand for targeted therapies, and the increased use of digital health technologies that support remote monitoring and patient-focused care (Liu et al., 2025; Panchpuri et al., 2025).

2. Evolution of Smart Drug Delivery Systems

The evolution of drug delivery systems can be traced through several distinct phases, each characterized by increasing sophistication in design and functionality (Gonzalez-Alvarez et al., 2021; Adepu & Ramakrishna, 2021). The first generation of controlled-release systems focused primarily on modifying the rate of drug release through matrix tablets, coated pellets, and reservoir systems. These systems, while representing a significant advancement over immediate-release formulations, lacked the ability to respond to physiological changes or target specific tissues (Gonzalez-Alvarez et al., 2021).

The second generation introduced the concept of targeted delivery, utilizing passive targeting mechanisms such as the enhanced permeability and retention (EPR) effect in tumor tissues, or active targeting through the incorporation of ligands that recognize specific cellular receptors (Prabahar et al., 2021). Liposomal formulations, introduced in the 1960s, exemplified this approach by improving drug stability and enabling preferential accumulation in certain tissues (Adepu & Ramakrishna, 2021).

The current third generation of smart drug delivery systems represents a quantum leap in sophistication, incorporating multiple responsive mechanisms, real-time monitoring capabilities, and the ability to adapt delivery parameters based on patient-specific factors. These systems utilize advanced materials such as stimuli-responsive polymers, magnetic nanoparticles, and bioengineered carriers that can respond to changes in pH, temperature, enzyme activity, or external stimuli.

Recent innovations have focused on the development of digital health-enabled delivery systems that integrate sensors, wireless communication, and artificial intelligence to provide personalized treatment regimens. Connected inhalers, which dominated the smart drug delivery market with $4.3 billion in revenue in 2024, exemplify this trend by incorporating Bluetooth capabilities, usage tracking, and real-time data sharing with healthcare providers.

3. Nanotechnology-Based Drug Delivery Platforms

Nanotechnology has become essential in contemporary smart drug delivery systems, providing exceptional possibilities for accurate therapeutic actions at the molecular and cellular scales. Nanoparticle-based delivery systems, usually between 1 and 100 nanometers, can be designed to bypass biological barriers, specifically target tissues or cells, and precisely control the release of therapeutic substances.

3.1 Lipid-Based Nanocarriers

Liposomes are the most successful nanocarriers in clinical applications, with many FDA-approved formulations in use. These spherical vesicles, made of phospholipid bilayers, provide great biocompatibility and can encapsulate both water-soluble and fat-soluble drugs. Recent progress has been made in creating pH-sensitive liposomes that release their contents in the acidic environment of tumors, improving drug delivery to cancer cells and reducing impact on healthy tissues.

Solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) are advanced lipid-based systems that provide better drug loading, controlled release, and increased stability. They are especially effective for delivering drugs with low water solubility and for applications needing prolonged release.

3.2 Polymeric Nanoparticles

Polymeric nanoparticles use biodegradable and biocompatible materials like poly(lactic-co-glycolic acid) (PLGA), polyethylene glycol (PEG), and chitosan to form adaptable drug delivery systems. These platforms allow for precise control over drug release by adjusting the polymer's composition, molecular weight, and degradation characteristics.

The integration of stimuli-responsive polymers has led to the creation of "smart" polymeric systems that react to specific physiological conditions. Polymers sensitive to pH can target the acidic environments found in tumors or inflamed tissues, while temperature-sensitive systems can be triggered by localized heat or natural temperature changes.

3.3 Inorganic Nanoparticles

Inorganic nanoparticles such as gold, silver, iron oxide, and silica-based systems possess distinct properties beneficial for drug delivery and imaging. Gold nanoparticles are especially noted for their use in photothermal therapy, whereas superparamagnetic iron oxide nanoparticles (SPIONs) facilitate magnetic targeting and enhance contrast in magnetic resonance imaging.

Quantum dots and carbon-based nanomaterials are emerging as promising platforms for drug delivery and real-time monitoring of therapeutic effects, thanks to their outstanding optical properties and the ability to be functionalized with targeting ligands and therapeutic agents.

3.4 Protein-Drug Conjugates

Protein-drug conjugates, like antibody-drug conjugates (ADCs), are an emerging class of targeted therapies that merge the precision of biological targeting with the effectiveness of cytotoxic drugs. These systems use monoclonal antibodies or other proteins to specifically deliver drugs to cells that express the target antigen. Recent FDA approvals, such as Kadcyla® (trastuzumab-DM1) for HER2-positive breast cancer and Abraxane® (albumin-bound paclitaxel) for various cancers, highlight the clinical success of this strategy.

4. Personalized Medicine and Precision Drug Delivery

Incorporating personalized medicine into drug delivery systems marks a significant departure from the conventional "one-size-fits-all" healthcare model. These systems are tailored to consider individual differences in genetics, metabolism, disease development, and lifestyle factors that affect treatment outcomes.

4.1 Pharmacogenomic-Guided Delivery

Pharmacogenomics, which examines how genetic differences influence drug responses, is crucial in shaping drug delivery system design. Variations in genes related to drug-metabolizing enzymes, transporters, and receptors can greatly affect drug effectiveness and safety. Intelligent delivery systems can be tailored to address these genetic differences by altering drug release rates, targeting particular cell groups, or changing pharmacokinetic characteristics.

4.2 3D Printing and Personalized Dosage Forms

Three-dimensional printing technology has transformed the creation of personalized medication forms with customized drug-release features. This innovation allows for the production of tablets with intricate internal designs, multiple drug sections, and individualized release patterns tailored to patient needs.
The FDA's approval of Spritam® (levetiracetam), the first drug product made using 3D printing, represented a major advancement in personalized medicine. Ongoing research aims to enhance 3D printing capabilities to include multiple drugs in one dosage form, develop patient-specific implantable devices, and integrate sensors for real-time monitoring.

5. Theranostic Systems: Combining Diagnosis and Therapy

Theranostics, blending "therapeutics" and "diagnostics," is an advanced method that merges diagnostic imaging with therapeutic treatment in one system. This allows for real-time tracking of drug delivery, evaluation of treatment effectiveness, and adjustment of treatment plans according to each patient's response.

5.1 Nuclear Medicine Theranostics

Nuclear medicine has led the way in theranostic advancements by using radiopharmaceutical pairs for both diagnosis and treatment. The effectiveness of lutetium-177 DOTATATE (Lutathera®) in treating neuroendocrine tumors, alongside gallium-68 DOTATATE for selecting patients and monitoring treatment, highlights the clinical promise of this method.

6. Biomarker-Guided Drug Delivery

Incorporating biomarker analysis into the design of drug delivery systems has facilitated the creation of precision therapies that can be customized to the specific characteristics of patients and disease subtypes. Biomarkers play various roles in intelligent drug delivery, such as selecting patients, monitoring treatment, and predicting outcomes.

6.1 Predictive Biomarkers

Predictive biomarkers help identify patients who will benefit most from certain treatments. In cancer therapy, biomarkers like HER2 overexpression, PD-L1 expression, and BRCA mutations are crucial for choosing patients for targeted treatments. Smart delivery systems can be developed to include these biomarker-targeting features, ensuring that therapeutic agents are directed specifically to cells with the relevant biomarkers, while avoiding normal tissues. .

7. Clinical Applications and Current Market Trends

Smart drug delivery systems are used in various therapeutic areas, with cancer treatment being the largest segment, making up 39.4% of applications. This is due to the significant benefits of targeted delivery in oncology, which allows for concentrating treatments at tumor sites while reducing systemic exposure.

7.1 Cancer Treatment

In oncology, smart delivery systems have enabled the development of targeted therapies that can overcome many of the limitations of conventional chemotherapy. Liposomal formulations of doxorubicin (Doxil®), paclitaxel (Abraxane®), and irinotecan (Onivyde®) have demonstrated improved therapeutic indices compared to their free drug counterparts.

In oncology, advanced delivery systems have facilitated the creation of targeted treatments that address many drawbacks of traditional chemotherapy. Liposomal versions of doxorubicin (Doxil®), paclitaxel (Abraxane®), and irinotecan (Onivyde®) have shown enhanced therapeutic effectiveness compared to their unencapsulated forms.

Recent advancements include antibody-drug conjugates, which merge the targeting precision of monoclonal antibodies with the cytotoxic power of chemotherapy drugs, and nanoparticle systems capable of delivering multiple therapeutic agents either simultaneously or in sequence.

7.2 Diabetes Management

Smart insulin delivery systems represent a rapidly growing application area, with the integration of continuous glucose monitoring and automated insulin delivery creating "artificial pancreas" systems. These closed-loop systems can adjust insulin delivery in real-time based on glucose levels, significantly improving glycemic control and reducing the risk of hypoglycemic episodes.

Table 1: Selected FDA-Approved Nanomedicines

Product Name	Nanoformulation	Active Ingredient	Indication	Approval Year
Abraxane®	Albumin-bound	Paclitaxel	Various cancers	2012
Onivyde®	Liposomal	Irinotecan	Pancreatic cancer	2015
Vyxeos®	Liposomal	Daunorubicin/Cytarabine	Acute myeloid leukemia	2017
Onpattro®	Lipid nanoparticles	siRNA	Transthyretin amyloidosis	2018
BNT162b2	Lipid nanoparticles	mRNA vaccine	COVID-19 prevention	2020

8. Regulatory Considerations and Fda Approvals

The regulatory framework for smart drug delivery systems has changed considerably. Regulatory bodies have crafted specific guidelines to assess nanotechnology-driven products and personalized medicine strategies. In 2024, the FDA approved 18 personalized medicines, accounting for 38% of all newly sanctioned therapeutic entities, highlighting the increasing regulatory endorsement of these cutting-edge therapeutic methods.

8.1 Regulatory Framework for Nanomedicines

The FDA has set forth particular guidance documents for assessing nanomedicines, focusing on areas like characterization needs, manufacturing oversight, and safety evaluation. These guidelines stress the necessity of thorough physicochemical characterization, which includes aspects like particle size distribution, surface characteristics, and stability in physiological environments.

9. Challenges and Limitations

Despite the major progress in intelligent drug delivery systems, various challenges and limitations still hinder their widespread clinical use and optimal effectiveness.

9.1 Manufacturing and Scalability

The creation of advanced nanoparticle-based delivery systems poses substantial difficulties related to reproducibility, scalability, and cost efficiency. The complexity of these systems, which frequently include numerous components and intricate assembly methods, makes it challenging to maintain consistent product quality on a commercial scale.

9.2 Safety and Toxicity Considerations

The enduring safety of nanomedicine products is still a matter of worry, especially concerning their potential build-up in tissues and organs. Although the majority of approved nanomedicines have shown satisfactory safety records, uncertainties persist about the long-term consequences of ongoing exposure to nanoparticles.

10. Future Perspectives And Emerging Technologies

The future landscape of smart drug delivery systems is marked by the merging of various cutting-edge technologies, such as artificial intelligence, advanced materials science, biotechnology, and innovations in digital health.

10.1 Artificial Intelligence and Machine Learning

The incorporation of artificial intelligence and machine learning algorithms into drug delivery systems is set to transform personalized medicine by allowing for the real-time optimization of treatment plans based on each patient's response. AI-driven systems can assess extensive datasets encompassing patient details, biomarker profiles, and treatment results to forecast the best dosing schedules and pinpoint patients who are most likely to gain from certain therapies.

10.2 Advanced Materials and Nanotechnology

Advancements in materials like DNA origami, protein-based nanocarriers, and biomimetic systems provide exciting opportunities for developing advanced delivery platforms. These platforms can be crafted with meticulous molecular-level precision concerning their structure, functionality, and targeting capabilities.

10.3 Wearable and Implantable Devices

The integration of drug delivery capabilities into wearable devices and implantable systems offers new possibilities for continuous, personalized therapy. These systems can provide real-time monitoring of physiological parameters and adjust drug delivery accordingly.

11. Discussion

The rapid evolution of smart drug delivery systems—driven by advances in nanotechnology, biomaterials, and personalized medicine—has fundamentally transformed pharmaceutical research and clinical practice. Despite remarkable progress, translating these innovations into widespread clinical use presents significant challenges and opportunities that warrant in-depth discussion.

One of the central themes emerging from recent research is the balance between technological sophistication and practical implementation. While third-generation delivery systems offer highly responsive, targeted, and adaptive therapies, their complexity also introduces substantial hurdles in manufacturing, scalability, and regulatory approval. The need for robust, standardized production methods and clear regulatory guidelines is paramount to facilitate the safe and effective adoption of these technologies in clinical settings.

Another critical consideration is patient-specific customization. The integration of pharmacogenomics, biomarker-guided targeting, and 3D-printed dosage forms holds tremendous promise for truly individualized therapy. However, integrating these approaches into routine healthcare requires advances in diagnostic infrastructure, data analytics, and cost-effectiveness analyses to ensure equitable access and clinical utility.

Theranostic systems, which combine real-time diagnosis and therapy, exemplify the convergence of precision medicine and digital health. These platforms enable continuous monitoring and treatment adjustment, but they also demand robust data security, patient privacy protections, and interdisciplinary collaboration among clinicians, engineers, and data scientists.

Safety and long-term biocompatibility remain unresolved issues, especially with the increasing use of complex nanomaterials. Ongoing studies must address the pharmacokinetics, toxicity, and potential environmental impacts of these systems. Transparent reporting and international collaboration are essential to build a trusted evidence base for future innovation.

Looking ahead, the multidisciplinary nature of smart drug delivery—requiring expertise in chemistry, biology, engineering, artificial intelligence, and clinical sciences—highlights the need for collaborative networks and cross-sector partnerships. By bridging gaps between research and application, the field can accelerate the translation of cutting-edge technologies into tangible benefits for patients, healthcare systems, and society at large.

12. Conclusion

Intelligent drug delivery systems signify a groundbreaking progression in pharmaceutical sciences, providing unmatched possibilities for tailored, precise, and efficient treatment methods. The fusion of nanotechnology, personalized medical strategies, and theranostic abilities has established a novel framework in healthcare, overcoming numerous constraints of traditional drug delivery techniques.

The swift expansion of the smart drug delivery systems market, anticipated to hit $48.3 billion by 2034, highlights the considerable clinical and commercial promise of these technologies. The growing regulatory acceptance, evidenced by the FDA's approval of 18 personalized medicines in 2024, serves as validation for the clinical effectiveness and safety of these advanced therapeutic methods.

Nevertheless, considerable obstacles persist regarding the scalability of manufacturing, the efficiency of targeting, safety evaluations, and cost-effectiveness. Overcoming these hurdles will necessitate ongoing advancements in materials science, manufacturing techniques, analytical approaches, and regulatory structures.

The future of intelligent drug delivery systems is rooted in the ongoing integration of several cutting-edge technologies, such as artificial intelligence, advanced materials, biotechnology, and advancements in digital health. The aim of this field is to create genuinely smart systems that can adjust to each patient's unique requirements, react to evolving physiological conditions, and enhance therapeutic results instantaneously.

As we progress, effectively integrating smart drug delivery systems into clinical settings will rely on the collaborative efforts of scientists, engineers, clinicians, and regulatory specialists from various disciplines. The potential advantages for patients, such as better treatment results, fewer side effects, and improved quality of life, strongly encourage ongoing investment and innovation in this swiftly advancing area.

References

Adepu, S., & Ramakrishna, S. (2021). Controlled drug delivery systems: Current status and future directions. Molecules, 26(19), 5905. https://doi.org/10.3390/molecules26195905

Alaghawani, N. A., Alkhatib, H., Elmancy, L., & Daou, A. (2024). Harmonizing innovations: An in-depth comparative review on the formulation, applications, and future perspectives of aerogels and hydrogels in pharmaceutical sciences. Gels, 10(10), 663. https://doi.org/10.3390/gels10100663

Boppana, S. H., Huang, L., Kumar, A., & Zhang, Y. (2024). Current approaches in smart nano-inspired drug delivery: A comprehensive review. Journal of Controlled Release, 368, 234-251. https://doi.org/10.1016/j.jconrel.2024.02.018

Burkett, B. J., Bartlett, R. M., Klain, M., & Pryma, D. A. (2023). A review of theranostics: Perspectives on emerging approaches and clinical opportunities. Annals of Nuclear Medicine, 37(3), 143-158. https://doi.org/10.1007/s12149-023-01825-6

Chen, D., Wang, L., Li, Y., & Zhang, H. (2024). Biomarkers navigate drug development: Pharmacology, therapeutic guidance, and precision medicine applications. Drug Discovery

Today, 29(2), 103847. https://doi.org/10.1016/j.drudis.2024.103847
Dri, D. A., Rinaldi, F., Carafa, M., & Marianecci, C. (2022). Nanomedicines and nanocarriers in clinical trials: Surfing through regulatory requirements and physico-chemical critical quality attributes. Pharmaceutics, 14(11), 2456. https://doi.org/10.3390/pharmaceutics14112456
Egwu, C. O., Audu, J. A., Abubakar, A., & Shehu, M. (2024). Nanomaterials in drug delivery: Strengths and opportunities in medicine. International Journal of Molecular Sciences, 25(11), 6023. https://doi.org/10.3390/ijms25116023
Global Market Insights. (2025). Smart drug delivery systems market size and forecast report 2025-2034. Retrieved from https://www.gminsights.com/industry-analysis/smart-drug-delivery-systems-market
Gonzalez-Alvarez, M., Gonzalez-Alvarez, I., & Bermejo, M. (2021). Controlled delivery formulations: New opportunities for oral drug administration. Pharmaceutics, 13(3), 435. https://doi.org/10.3390/pharmaceutics13030435
Hapuarachchige, S., Kato, Y., & Artemov, D. (2020). Theranostic pretargeting drug delivery and imaging with click chemistry. Molecular Pharmaceutics, 17(7), 2217-2232. https://doi.org/10.1021/acs.molpharmaceut.0c00278
Islam, S., Rahman, M., Ahmed, K., & Hassan, P. (2025). Advances in nanoparticles in targeted drug delivery–A review. Materials Today Communications, 42, 108234. https://doi.org/10.1016/j.mtcomm.2025.108234
Kumarasamy, R. V., Bhatt, S., Jha, A., & Kumar, P. (2024). Nanomedicine in cancer therapy: A comprehensive review on completed human clinical trials. Frontiers in Nanotechnology, 6, 1479993. https://doi.org/10.3389/fnano.2024.1479993
Liu, M., Chen, J., Wang, X., & Li, Y. (2025). Nano-based drug delivery systems for managing diabetes: Recent advances and future perspectives. International Journal of Nanomedicine, 20, 245-263. https://doi.org/10.2147/IJN.S425789
Mazayen, Z. M., Ghoneim, A. M., & El-Diasty, F. (2022). Pharmaceutical nanotechnology: From the bench to the market. Journal of Controlled Release, 343, 316-340. https://doi.org/10.1016/j.jconrel.2022.01.035
Mitchell, M. J., Billingsley, M. M., Haley, R. M., Wechsler, M. E., Peppas, N. A., & Langer, R. (2021). Engineering precision nanoparticles for drug delivery. Nature Reviews Drug Discovery, 20(2), 101-124. https://doi.org/10.1038/s41573-020-0090-8
Panchpuri, M., Singh, R., & Sharma, V. (2025). Artificial intelligence in smart drug delivery systems: Current applications and future perspectives. Physical Chemistry Chemical Physics, 27(8), 6234-6251. https://doi.org/10.1039/D5PM00089K
Peng, H., Liu, X., Wang, Y., & Zhou, L. (2024). 3D printing processes in precise drug delivery for personalized medicine applications. Additive Manufacturing, 82, 104067. https://doi.org/10.1016/j.addma.2024.104067
Personalized Medicine Coalition. (2025). Personalized medicine at FDA: The scope & significance of progress in 2024. Washington, DC: PMC.
Prabahar, K., Udupa, N., & Umadevi, P. (2021). Targeted drug delivery system: Advantages, carriers and strategies. Indian Journal of Pharmaceutical Education and Research, 55(2), 346-358. https://doi.org/10.5530/ijper.55.2.72
Puccetti, M., Paolicelli, P., Petralito, S., & Casadei, M. A. (2024). Biologics, theranostics, and personalized medicine in drug delivery: Current applications and future perspectives. Journal of Personalized Medicine, 14(3), 306. https://doi.org/10.3390/jpm14030306
Sanchez-Moreno, P., Ortega-Vinuesa, J. L., & Martin-Rodriguez, A. (2024). Smart drug-delivery systems for cancer nanotherapy: Recent advances and clinical perspectives. Advanced Healthcare Materials, 13(8), 2301254. https://doi.org/10.1002/adhm.202301254
Singh, K., Patel, R., & Kumar, A. (2024). Nanomedicine and drug delivery: A comprehensive review of current applications and future directions. Materials Today Bio, 25,

100943.
https://doi.org/10.1016/j.mtbio.2024.100943
Trucillo, P., Campardelli, R., & Reverchon, E. (2024). Biomaterials for drug delivery and human applications: Current advances and future perspectives. Biomaterials, 321, 122089. https://doi.org/10.1016/j.biomaterials.2024.122089
World Health Organization. (2023). Noncommunicable diseases: Key facts. Geneva: WHO Press.
Yetisgin, A. A., Cetinel, S., Zuvin, M., Kosar, A., & Kutlu, O. (2020). Therapeutic nanoparticles and their targeted delivery applications. Molecules, 25(9), 2193. https://doi.org/10.3390/molecules25092193
Zhang, Y. B., Wang, L., Chen, X., & Liu, H. (2024). Nano-based drug delivery systems for active ingredients from traditional Chinese medicine: Current advances and clinical applications. Frontiers in Pharmacology, 15, 1405252. https://doi.org/10.3389/fphar.2024.1405252