Global Insights in Biomedical & Multidisciplinary Research (GIBMR)
Volume 01, Issue 01, March-2026
Available Online at: https://biomedglobe.com/index.php/gibmr
ISSN (Online): XXXX-XXXX

Nanotechnology in Targeted Drug Delivery Systems: Advances, Challenges, and Clinical Prospects

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Article History	Abstract
Received: 10th January, 2026 Accepted: 25th February, 2026	Nanotechnology has emerged as a transformative field in biomedical science, particularly in the development of targeted drug delivery systems. Nanoparticles offer significant advantages such as improved drug solubility, enhanced bioavailability, and precise delivery of therapeutic agents to diseased tissues. These characteristics reduce systemic toxicity and improve therapeutic outcomes. Various nanocarriers including liposomes, polymeric nanoparticles, dendrimers, and metallic nanoparticles have been developed for medical applications. This review discusses recent advances in nanotechnology-based drug delivery systems, their biomedical applications, and the challenges associated with clinical translation. The study highlights the potential of nanomedicine to revolutionize modern therapeutics while emphasizing the need for improved safety evaluation and regulatory frameworks.

Keywords: Nanotechnology, drug delivery, nanoparticles, nanomedicine, targeted therapy

1. Introduction

Drug delivery systems play a crucial role in determining the therapeutic effectiveness of pharmaceutical compounds. Conventional drug administration methods often suffer from limitations such as poor bioavailability, rapid degradation, and non-specific distribution within the body.

Nanotechnology offers innovative solutions to these challenges by enabling the design of nanoscale carriers capable of delivering drugs directly to target tissues. Nanoparticles typically range from 1 to 100 nanometers in size and possess unique physicochemical properties that enhance drug stability and therapeutic efficiency.

In recent years, significant progress has been made in developing nanocarrier systems capable of delivering drugs to specific cells, thereby minimizing side effects and improving treatment outcomes.

2. Types of Nanocarriers

2.1 Liposomes

Liposomes are spherical vesicles composed of lipid bilayers. They are widely used as drug carriers due to their biocompatibility and ability to encapsulate both hydrophilic and hydrophobic drugs.

Liposome-based formulations have been successfully used in cancer therapy, allowing targeted delivery of chemotherapeutic agents to tumor tissues.

2.2 Polymeric Nanoparticles

Polymeric nanoparticles are constructed from biodegradable polymers such as PLGA (poly-lactic-co-glycolic acid). These nanoparticles offer controlled drug release and improved stability.

They have been extensively studied for delivering anticancer drugs, vaccines, and gene therapies.

2.3 Dendrimers

Dendrimers are highly branched macromolecules with well-defined structures. Their unique architecture allows them to carry multiple drug molecules simultaneously.

Dendrimers have shown promising results in gene delivery and targeted cancer therapies.

2.4 Metallic Nanoparticles

Metallic nanoparticles such as gold and silver nanoparticles possess unique optical and electronic properties. These particles are increasingly used in diagnostic imaging and targeted drug delivery.

Gold nanoparticles, in particular, are widely investigated for cancer treatment due to their ability to accumulate in tumor tissues.

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3. Biomedical Applications

3.1 Cancer Therapy

Nanoparticle-based drug delivery systems have demonstrated improved effectiveness in cancer treatment. Targeted nanocarriers can selectively deliver chemotherapeutic agents to tumor cells while reducing toxicity to healthy tissues.

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3.2 Gene Therapy

Nanoparticles can transport genetic material such as DNA and RNA into cells, making them valuable tools for gene therapy. This approach has the potential to treat genetic disorders and certain types of cancer.

3.3 Vaccine Delivery

Nanotechnology-based vaccine delivery systems enhance immune responses by improving antigen stability and targeted delivery to immune cells.

3.4 Antimicrobial Applications

Nanoparticles have demonstrated antimicrobial properties and are being explored as potential solutions for combating antibiotic-resistant pathogens.

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4. Advantages of Nanotechnology in Drug Delivery

Enhanced Drug Stability

Nanocarriers protect drugs from premature degradation within the body.

Controlled Drug Release

Nanoparticles allow controlled release of drugs over extended periods.

Targeted Delivery

Targeted drug delivery improves therapeutic outcomes and reduces adverse effects.

Improved Bioavailability

Nanoparticles enhance the absorption and distribution of poorly soluble drugs.

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5. Challenges and Limitations

Despite its potential, nanomedicine faces several challenges that must be addressed before widespread clinical adoption.

Toxicity Concerns

Some nanoparticles may accumulate in organs and cause long-term toxicity.

Manufacturing Complexity

Large-scale production of nanoparticles with consistent quality remains challenging.

Regulatory Barriers

Nanomedicine requires new regulatory frameworks to ensure safety and efficacy.

High Development Costs

Developing nanoparticle-based therapeutics can be expensive due to complex research and testing requirements.

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6. Future Perspectives

The future of nanotechnology in medicine is highly promising. Advances in materials science, biotechnology, and computational modeling will enable the design of more sophisticated nanocarriers.

Personalized nanomedicine may allow drugs to be tailored to individual patients based on genetic and molecular profiles. Additionally, integration of nanotechnology with artificial intelligence could further enhance drug design and delivery efficiency.

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7. Conclusion

Nanotechnology has opened new avenues in targeted drug delivery and biomedical research. By improving drug stability, bioavailability, and targeting efficiency, nanocarrier systems have the potential to transform modern therapeutics. Continued research and interdisciplinary collaboration will be essential to overcome current challenges and ensure safe clinical translation of nanomedicine technologies.

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