Research Output Journal of Biological and Applied Science 4(3):47-50, 2024

ROJBAS Publications ONLINE ISSN: 1115-9200

https://rojournals.org/roj-biological-and-applied-science/ PRINT ISSN: 1115-6120

https://doi.org/10.59298/ROJBAS/2024/434750

Engineering Solutions for Drug Delivery Systems

Amina Nalongo J.

Faculty of Engineering Kampala International University Uganda

ABSTRACT

This paper examines the evolution of engineering solutions in drug delivery systems, emphasizing the role of nanotechnology in overcoming current challenges in precision medicine. It addresses key challenges in drug delivery, including targeting specificity, minimizing adverse effects, and enhancing the efficiency of drug carriers. Both top-down and bottom-up engineering approaches are examined, with case studies highlighting successful applications in cancer therapy, gene delivery, and implantable devices. The paper also investigates future trends, such as smart and active delivery systems, and discusses the interdisciplinary collaboration required for these advances. By integrating material science, bioengineering, and pharmaceutical technology, this research presents innovative solutions aimed at improving therapeutic efficacy and minimizing toxicity.

Keywords: Drug delivery systems, Nanotechnology, Top-down engineering, Bottom-up engineering, Gene therapy, Smart drug delivery.

INTRODUCTION

The release of a pharmaceutical product from its dosage must result in its rapid movement within the patient's body to reach the target site for optimal pharmacological activity. Ideally, the free drug in the body should be below its toxic concentration and high enough for the required therapeutic effect. Perhaps the perfect drug delivery system would consist of drugs that were released to fit the patient's needs by a switch: on or off. This is the basic requirement for an ideal drug delivery system, but in practice, it's far more complex. In our complex and ever-changing world, the design of the correct drug delivery system requires multidisciplinary scientific knowledge and creativity. Scientists from fields such as materials science, pharmaceuticals, engineering, biology, chemistry, and electronics would collaborate to deliver the required concept for its clinical use. The final product should be a multimode therapeutic delivery system that provides the delivery of informative drugs, control of drug release, and quantitative control of release and delivery based on therapeutic needs. This requires the implementation of a new area of work that is of considerable importance to the creation of truly effective drug delivery systems, a challenging field known as nanotechnology [1, 2].

Major Challenges in Drug Delivery Systems

High specificity and low adverse reaction anti-cancer delivery is an important research area due to the severe side effects of conventional treatments. Although small interfering RNA materials present outstanding gene regulation potential, their poor transfection effectiveness and high dosage are problematic for cells. In this work, we prepared polymeric nanoparticles combined with ferric nanoparticles through emulsion hydrophobic solvent-soluble nanoparticle formation. The carriers enhanced cell electroporation of siRNA, in which the applied field was 100 V/mm, duration 10 ms, and the electric cell transmembrane potential reached 1.2 V. In vitro and in vivo animal model testing showed that enabled excellent gene knockdown for PTEN-overexpressing MCF7 cells [3, 4]. Key challenges in drug delivery are longevity, immunogenicity, and toxicity of delivery carriers as well as targeting efficiency. Therefore, drug delivery systems must offer both high cell-penetrating efficacy and endosomal escape for heterogeneous cell phenotype regulation therapy. The recent research trend of non-viral

delivery of genetic material focuses on using cationic polymers. Meanwhile, polyethylene glycol is introduced along with the cationic polymers to expand in vivo application efficacies, giving rise to the PEGylated core nanoparticles for siRNA delivery for relevant in vitro application for gene therapy [5, 6].

Engineering Approaches and Innovations

a. Top-Down Engineering

Top-down approaches include many engineering perspectives such as mechanical, electrical, chemical, and systems engineering, as well as computer modeling and bioengineering. Thus, combining these technologies produces a synergetic innovation in drug delivery. Currently, within the pharmaceutical product roadmap, the highly interdisciplinary concept of nanomedicine, combining drug and nanotechnology, is the most promising for achieving targeted drug delivery. An engineering community brings new technologies, such as novel stents, electrodes, and particles, to future markets for better solutions for specific targeted diseases. An engineering approach still does not properly solve controversial issues, typically localization of nanoparticles, endosomal escape, and safety risks, because these issues are deeply coupled with fundamental life sciences. Therefore, in engineering fields, great efforts on the bench and further collaboration with life scientists are needed [7, 8].

b. Bottom-Up Engineering

Most top-down products are made via multi-stage top-down processes such as fine patterning, crack formation, and sintering of their dimensions; these cause a size limit in fabricating products. In contrast, bottom-up technologies, such as self-assembly or supramolecular chemistry, obey the intrinsic law of nature. An innovative concept of bottom-up approaches can design products by self-organization based on specific resources and scaffolds. For example, in oral, rectal, and dermal drug delivery, guanosine microcrystals maintain the invasion of drugs in biological membranes. The use of natural products, intelligent use of physicochemical requirements of disease target particles, and the cooperative effect of biology can additionally increase the efficiency of drug carriers [9, 10].

Case Studies and Applications

Case studies and examples are necessary to test and demonstrate the effectiveness and efficiency of the above conceptual models and methods. In this section, we discuss four drug repositioning case studies to demonstrate how to design a novel target-specific drug delivery system for a specific disease. These industrial case studies illustrate how to address the delivery limitations from the pharmacokinetic, pharmacodynamic, chemical, balance, toxicity, and pathway perspectives with the careful treatment combination effect. In the first case, two targets are examined and a delivery route is designed for treating glioblastoma. In the second case, we explore the interaction between miRNA and tumor initiation and design a double-target therapy for stem cell maintenance and redifferentiation in breast cancer. The third case first clarifies the TCR and PTEN molecular mechanisms and designs a dendritic cell-targeted peptide vaccine. In the last case study, we conducted a metformin repositioning study for gastric cancer and identified the novel therapeutic schedules of targeted therapies based on important pathway disequilibrations. Some suggestions for future research are given. We hope that the solutions and methods based on the conceptual model will greatly help biologists, pharmacologists, toxicologists, and pharmaceutical researchers [11, 12].

Future Trends and Opportunities

Active implantable drug delivery systems constitute a different class of drug delivery systems from the perspective of materials or dimensions. Miniaturized and intravascular devices mainly use microsystems technology to deliver a drug to a specific location within the body due to electric, pressure, or temperature mediation. Recognizing the territory as broad, we kept a clear distinction here not to fall into the trap of using an all-inclusive approach to device strategies. Thus, we did not discuss electric-controlled devices, which are already widely discussed. Their area will most likely grow in importance with further development of species-specific drugs, test chips for in vivo drug evaluation studies, implantable devices, and micromachined peripherals [13, 14]. Limited materials compatibility, multifunctional group syntheses, bio instrumentation, realization of the calculated in vivo pharmacoproperties preselection, microsystems technologies, and animal benefit-cost studies represent current limits to the further collaborative development and practical usefulness of these active implantable drug delivery systems. We believe that increasing the in vivo specificity of drug action through liposome surface chemistry and micro-delivery systems will produce, in a shorter time, the sort of multidisciplinary team breakthroughs that are currently achievable only in gene replacement research.

We have summarized this chapter by describing the many engineering opportunities that exist in formulating gene therapy drugs for in vivo applications [15, 16].

CONCLUSION

The field of drug delivery systems has advanced significantly, driven by interdisciplinary engineering innovations and nanotechnology. Both top-down and bottom-up engineering approaches provide unique solutions to overcome challenges in drug targeting, release mechanisms, and safety. The successful application of these strategies is demonstrated in various therapeutic areas, particularly in cancer and gene therapy. However, challenges such as immunogenicity, long-term safety, and precision targeting remain, requiring further collaboration between engineers, biologists, and medical researchers. Future trends point toward the development of smart, miniaturized, and implantable drug delivery systems, enhancing therapeutic outcomes and reducing side effects. Continuous innovation and interdisciplinary teamwork are key to unlocking the full potential of next-generation drug delivery systems.

REFERENCES

1. Sahu T, Ratre YK, Chauhan S, Bhaskar LV, Nair MP, Verma HK. Nanotechnology-based drug delivery system: Current strategies and emerging therapeutic potential for medical science. Journal of Drug Delivery Science and Technology. 2021 Jun 1;63:102487. [HTML]
2. Ezike TC, Okpala US, Onoja UL, Nwike CP, Ezeako EC, Okpara OJ, Okoroafor CC, Eze SC, Kalu OL, Odoh EC, Nwadike UG. Advances in drug delivery systems, challenges and future directions. Heliyon. 2023 Jun 1;9(6). cell.com
3. Fang X, Cao J, Shen A. Advances in anti-breast cancer drugs and the application of nano-drug delivery systems in breast cancer therapy. Journal of Drug Delivery Science and Technology. 2020 Jun 1;57:101662.
4. Kashkooli FM, Soltani M, Souri M. Controlled anti-cancer drug release through advanced nano-drug delivery systems: Static and dynamic targeting strategies. Journal of controlled release. 2020 Nov 10;327:316-49.
5. Kumar A, Zhou L, Zhi K, Raji B, Pernell S, Tadrous E, Kodidela S, Nookala A, Kochat H, Kumar S. Challenges in biomaterial-based drug delivery approach for the treatment of neurodegenerative diseases: Opportunities for extracellular vesicles. International Journal of Molecular Sciences. 2020 Dec 25;22(1):138. mdpi.com
6. Abasian P, Shakibi S, Maniati MS, Nouri Khorasani S, Khalili S. Targeted delivery, drug release strategies, and toxicity study of polymeric drug nanocarriers. Polymers for Advanced Technologies. 2021 Mar;32(3):931-44. [HTML]
7. Zhao Q, Cheng N, Sun X, Yan L, Li W. The application of nanomedicine in clinical settings. Frontiers in Bioengineering and Biotechnology. 2023 Jun 27;11:1219054.
8. Thorat ND, Townley HE, Patil RM, Tofail SA, Bauer J. Comprehensive approach of hybrid nanoplatforms in drug delivery and theranostics to combat cancer. Drug Discovery Today. 2020 Jul 1;25(7):1245-52. ox.ac.uk
9. Hao W, Cha R, Wang M, Zhang P, Jiang X. Impact of nanomaterials on the intestinal mucosal barrier and its application in treating intestinal diseases. Nanoscale Horizons. 2022;7(1):6-30.
10. Hani U, Honnavalli YK, Begum MY, Yasmin S, Osmani RA, Ansari MY. Colorectal cancer: A comprehensive review based on the novel drug delivery systems approach and its management. Journal of drug delivery science and technology. 2021 Jun 1;63:102532.
11. Meenakshi DU, Nandakumar S, Francis AP, Sweety P, Fuloria S, Fuloria NK, Subramaniyan V, Khan SA. Deep Learning and Site-Specific Drug Delivery: The Future and Intelligent Decision Support for Pharmaceutical Manufacturing Science. Deep Learning for Targeted Treatments: Transformation in Healthcare. 2022 Sep 16:1-38. [HTML]
12. Tanabe M, Sakate R, Nakabayashi J, Tsumura K, Ohira S, Iwato K, Kimura T. A novel in silico scaffold-hopping method for drug repositioning in rare and intractable diseases. Scientific Reports. 2023 Nov 8;13(1):19358. nature.com
13. Zhang H, Fan T, Chen W, Li Y, Wang B. Recent advances of two-dimensional materials in smart drug delivery nano-systems. Bioactive Materials. 2020 Dec 1;5(4):1071-86.
14. Mariello M, Eş I, Proctor CM. Soft and flexible bioelectronic micro-systems for electronically controlled drug delivery. Advanced Healthcare Materials. 2024 Sep;13(24):2302969.

15. Smith M, Roberts M, Al-Kassas R. Implantable drug delivery systems for the treatment of osteomyelitis. Drug Development and Industrial Pharmacy. 2022 Oct 3;48(10):511-27. tandfonline.com
16. Morsada Z, Hossain MM, Islam MT, Mobin MA, Saha S. Recent progress in biodegradable and bioresorbable materials: From passive implants to active electronics. Applied Materials Today. 2021 Dec 1;25:101257. [HTML]

CITE AS: Amina Nalongo J. (2024). Engineering Solutions for Drug Delivery Systems. Research Output Journal of Biological and Applied Science 4(3):47-50. https://doi.org/10.59298/ROJBAS/2024/434750