Polymers: Advancing smart, personalized drug delivery.

Pierre Lefevre*

Department of Chemical Engineering, University of Grenoble, France

Introduction

Polymers have become indispensable in modern pharmaceutical science, particularly in the advancement of drug delivery systems. The development of polymer-based nanocarriers, for example, marks a significant stride towards more effective and safer therapies. These systems are engineered to specifically target diseased cells, which directly improves drug efficacy while simultaneously reducing systemic side effects. The versatility of polymers allows for various structural modifications, enabling precise control over drug release kinetics and enhancing overall bioavailability, a critical aspect for developing advanced pharmaceutical formulations [1].

This targeting capability is further exemplified by the application of polymeric nanoparticles in cancer treatment. Such nanoparticles can be meticulously engineered to deliver therapeutic agents directly to tumor sites, which effectively minimizes toxicity to healthy tissues and significantly boosts treatment efficacy. Various polymer types and surface modification strategies are continuously explored to refine these targeted approaches [5]. Building on this, polymeric micelles also demonstrate substantial potential as nanocarriers, especially for improving the solubility and bioavailability of hydrophobic drugs. Their inherent design flexibility and self-assembly characteristics are key attributes, although ongoing research addresses challenges related to their stability and successful clinical translation [9].

A crucial subset of these materials includes biodegradable polymers, which are central to modern drug delivery. These polymers are designed not only for controlled drug release but also for their successful journey from laboratory to clinical application. They play a vital role in enhancing therapeutic outcomes by ensuring sustained drug levels within the body and reducing the risk of systemic toxicity [2]. Beyond active delivery, polymers also serve as critical excipients. Specifically, polymeric excipients are fundamental to amorphous solid dispersions (ASDs), a widely adopted strategy to enhance the solubility and bioavailability of poorly water-soluble drugs. Recent innovations in polymer selection have been instrumental in stabilizing the amorphous drug form, thereby preventing recrystallization and significantly improving drug dissolution rates [3].

Expanding the utility of polymers, hydrogel-based systems offer diverse applications in both drug delivery and tissue engineering. Their tunable properties, intrinsic biocompatibility, and capacity to mimic the extracellular matrix make them exemplary scaffolds. These characteristics are invaluable for achieving controlled drug release and fostering cell growth in regenerative medicine [4]. For chronic conditions, polymer-based long-acting injectable formulations are transforming patient compliance and therapeutic adherence. These systems are designed to deliver sustained therapeutic effects over extended periods, overcoming various formulation challenges and demonstrating considerable success in clinical settings [7]. Further sophistication comes from stimuli-responsive polymers, often termed 'smart' polymers. These advanced materials enable drug release with remarkable precision, reacting to specific environmental cues such as pH, temperature, or light. This offers unparalleled control over drug kinetics and significantly enhances therapeutic specificity [8].

Innovations in manufacturing processes are also impacting polymeric drug delivery. Three-dimensional (3D) printing, an additive manufacturing technique, is opening new horizons for personalized medicine. It provides exact control over dosage, release profiles, and the complex geometries of pharmaceutical devices, paving the way for highly customized therapies [6]. Finally, the growing importance of biopolymers in pharmaceutical formulations cannot be overstated. Driven by their inherent biocompatibility, biodegradability, and natural origins, biopolymers are increasingly utilized as excipients, drug carriers, and formulation aids. This emphasis on biopolymers aligns with a broader push towards sustainable and patient-friendly drug development practices [10].

Conclusion

Polymers are pivotal in advancing drug delivery systems, enabling precise targeting and controlled release for enhanced therapeutic outcomes. Polymer-based nanocarriers, including micelles and nanoparticles, are engineered to deliver drugs specifically to diseased cells, like in cancer therapy, improving efficacy and minimizing side effects by modifying polymer structures for controlled release and better bioavailability. Biodegradable polymers are cru-

***Correspondence to:** Pierre Lefevre, Department of Chemical Engineering, University of Grenoble, France. E-mail: pierre.lefevre@univ-grenoble.fr

Received: 03-Jul-2025, Manuscript No. AAPCCS-25-193; **Editor assigned:** 07-Jul-2025, Pre QC No. AAPCCS-25-193 *(PQ)*; **Reviewed:** 25-Jul-2025, QC No. AAPCCS-25-193; **Revised:** 05-Aug-2025, Manuscript No. AAPCCS-25-193 *(R)*; **Published:** 14-Aug-2025, DOI: 10.35841/aapccs-9.3.193

Citation: Lefevre P. Polymers: Advancing smart, personalized drug delivery. J Pharm Chem Chem Sci. 2025;09(03):193.

cial, designed for controlled release, sustained drug levels, and reduced systemic toxicity, moving successfully into clinical applications. Beyond active delivery, polymers function as essential excipients, particularly in amorphous solid dispersions, to boost the solubility and bioavailability of poorly water-soluble drugs by stabilizing the amorphous form. Hydrogel-based systems are versatile, serving both drug delivery and tissue engineering due to their biocompatibility and ability to mimic biological matrices. Advanced systems include long-acting injectable formulations, which improve patient compliance with sustained effects, and stimuli-responsive 'smart' polymers that precisely release drugs based on environmental cues like pH or temperature. Manufacturing innovations like 3D printing are further enabling personalized medicine through customizable drug devices. Lastly, biopolymers are increasingly utilized in pharmaceutical formulations for their biocompatibility, biodegradability, and natural origin, supporting sustainable and patient-friendly drug development.

References

1. Mahdieh A, Reza A, Seyedeh Somayeh K. Recent Advances in Polymer-Based *Nanocarriers for Targeted Drug Delivery Systems. Polymers.* 2023;15:2486.
2. Yuxin Z, Guopeng W, Mengmeng Z. Biodegradable Polymers in Drug Delivery Systems: *From Design to Clinical Applications. Pharmaceutics.* 2022;14:2351.
3. Fangting Y, Rui W, Longfei W. Polymeric Excipients for Amorphous Solid Dispersions: *A Review of Recent Progress and Future Perspectives. Polymers.* 2022;14:3073.
4. Bairong L, Hao Y, Yongqian G. Hydrogel-based polymeric systems in drug delivery and tissue engineering: *A comprehensive review. Biomater Sci.* 2020;8:5240-5262.
5. Prachi K, Priyanka M, Sneha J. Polymeric Nanoparticles for Targeted Cancer Drug Delivery: *A Review of Recent Developments. Curr Drug Targets.* 2021;22:288-306.
6. Zhaojun W, Xinghua S, *Kaiyao Z.* 3D Printing of Polymeric Drug Delivery Systems: Current State and Future Perspectives. Molecules. 2021;26:970.
7. Jin-Wook L, Hyun-Joo P, Mi-Kyung K. Polymer-Based Long-Acting Injectable Formulations: *A Review on Recent Advancements and Clinical Applications. Polymers.* 2022;14:2824.
8. Jialin S, Shuzhen Z, Yunxuan C. Stimuli-Responsive Polymers for Drug Delivery: *A Comprehensive Review. Polymers.* 2023;15:188.
9. Yanhua D, Jing W, Yuqing W. Recent Advances in Polymeric Micelles for Drug Delivery: *Opportunities and Challenges. ACS Appl Polym Mater.* 2023;5:8632-8650.
10. Divya G, Anju G, Amita K. Biopolymers in Pharmaceutical Formulations: *An Overview of Recent Developments and Applications. J Polym Environ.* 2022;30:1779-1798.

Citation: *Lefevre P. Polymers: Advancing smart, personalized drug delivery. J Pharm Chem Chem Sci. 2025;09(03):193.*