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Editorial

From chemistry to clinic: The transformative role of nanofibers in cancer management

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Abstract

Nanofiber technology has emerged as a transformative platform in the realm of cancer therapeutics, bridging the disciplines of polymer chemistry, materials science, and biomedical engineering. This editorial highlight the multifaceted roles nanofibers play in cancer management, emphasizing how chemistry-driven design enables targeted, responsive, and sustained drug delivery systems. The editorial explores the application of nanofiber systems across diverse cancer types including brain, breast, lung, liver, colorectal, and gynaecological cancers showcasing their adaptability to organ-specific challenges and tumor microenvironments. Despite significant advancements, challenges related to scalability, regulatory approval, long-term safety, and cost-effectiveness remain.

Keywords: Nanofiber, Polymers, Drug delivery, Targeted delivery, Oncology.

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At this multidisciplinary interface, nanofibers have emerged as a promising and versatile tool for targeted drug delivery, localized treatment, and tissue regeneration.[1] The collection of scientific contributions under discussion in this compilation reflects a growing body of work that advances our understanding of how chemistry-driven design can create highly functional nanofiber systems tailored for various forms of cancer.[2]

1. The Chemical Foundation: Designing with Purpose

At the heart of nanofiber technology lies polymer chemistry the very blueprint that dictates structural and functional behaviour. The chemical makeup of the fibres determines not only their mechanical integrity but also their interaction with biological systems.[3] Surface groups such as hydroxyl, amine, and carboxyl moieties play critical roles in cellular recognition, drug attachment, and degradation behaviour. Moreover, at the nanoscale, chemical interactions electrostatic forces, hydrogen bonding, and hydrophobic interactions enable tunable performance.[4,5]

2. A Versatile Material Palette: Synthetic and Natural Polymers

A defining strength of nanofiber systems is their ability to integrate a wide spectrum of synthetic and natural polymers. Polymers such as PLGA, PCL, and PEG are widely used for their well-characterized degradation profiles and mechanical properties, while naturally derived materials like chitosan, gelatin, and alginate offer superior biocompatibility and mucoadhesive.[6]

3. Fabrication: Where Chemistry and Process Converge

Nanofiber production, particularly through electrospinning, is not merely a mechanical process but a chemically sensitive one. Solvent–polymer interactions, polymer chain entanglement, and solution conductivity all contribute to the final morphology of the fiber mat. Adjusting these parameters allows for control over diameter, porosity, and surface area—attributes directly tied to drug encapsulation and release behaviours.[7]

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4. Functionalization and Targeting: The Chemistry of Precision

Surface modification is where nanofibers truly bridge the gap between materials science and precision medicine. Chemical techniques such as click chemistry, EDC/NHS coupling, and thiol–maleimide conjugation allow for the attachment of targeting ligands including folic acid, antibodies, peptides, and aptamers providing tumor-specific binding and uptake.[8]

5. Targeted Applications across Cancer Types

One of the most compelling aspects of recent nanofiber research is its organ-specific adaptability. This compilation presents several advanced nanofiber strategies engineered to address these complexities across a range of malignancies.[9]

In the context of brain tumors, the blood–brain barrier remains a formidable obstacle. Nanofiber scaffolds designed for intracranial implantation post-surgery offer localized chemotherapy and tissue support.[10]

For colorectal and prostate cancers, the emphasis shifts to mucoadhesion and hormonal responsiveness. Nanofiber platforms that adhere to the intestinal mucosa or deliver hormone-based therapeutics directly to the prostate offer a new standard in localized therapy. These systems reduce systemic exposure and improve patient compliance through sustained-release mechanisms.[11]

In pancreatic and liver cancers, where tumors are often deeply embedded and resistant to treatment, nanofibers offer a dual advantage: penetration and persistence.[12]

6. Navigating the Translational Pathway: Challenges and Future Directions

Despite their promise, nanofiber-based therapeutics face several challenges on the road to clinical adoption. These include issues of scalability, regulatory classification, and cost-effectiveness.

1. Scalability remains a hurdle. While electrospinning is highly versatile, industrial-scale production requires innovations in throughput and quality control. The translation of lab-based prototypes to GMP-compliant systems must be supported by robust standardization and batch consistency.[13]
2. Regulatory ambiguity also persists. Nanofibers often fall between pharmaceutical and device categories, complicating approval processes. Clearer regulatory frameworks and validated testing protocols are essential for accelerating clinical trials.[14]

7. Conclusion

The evolution of nanofiber technology illustrates how chemical innovation can be harnessed to solve some of the most pressing challenges in oncology. These materials are no longer seen merely as passive scaffolds or slow-release platforms. Instead, they are active, adaptable tools designed with precision, tailored for interaction, and poised to transform how cancer is treated at the cellular and systemic level.

8. Conflict of Interest

None.

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