National Journal of Pharmaceutical Sciences 2024; 4(1): 53-57

National Journal of Pharmaceutical Sciences

E-ISSN: 2788-9270
P-ISSN: 2788-9262
www.pharmajournal.net
NJPS 2024; 4(1): 53-57
Received: 16-02-2024
Accepted: 20-03-2024

Nanofibers: A novelistic approach of drug delivery system

Raslamol K, Aleena Tony K, Devana AB, Edwin ML and Sandhra Rose Wilson

Raslamol K
Professor and HOD,
Department of Pharmaceutics,
Nirmala College of Health
Science, Chalakkudy, Kerala,
India

Aleena Tony K
Students, Nirmala College of
Health Science, Chalakkudy,
Kerala, India

Devana AB
Students, Nirmala College of
Health Science, Chalakkudy,
Kerala, India

Edwin ML
Students, Nirmala College of
Health Science, Chalakkudy,
Kerala, India

Sandhra Rose Wilson
Students, Nirmala College of
Health Science, Chalakkudy,
Kerala, India

Corresponding Author:
Raslamol K
Professor and HOD,
Department of Pharmaceutics,
Nirmala College of Health
Science, Chalakkudy, Kerala,
India

Abstract

Recent advancements in drug delivery systems have aimed to improve therapeutic efficacy, patient adherence, and minimize adverse effects. Nanotechnology has emerged as a forefront in this endeavor, particularly with nanofibers, which offer distinct advantages. Nanofibers, known for their high surface area-to-volume ratio, versatile functionalization options, and remarkable mechanical properties, provide unprecedented opportunities for precise and targeted drug delivery. Fabricated using techniques like electrospinning, nanofibers enable meticulous customization to meet specific drug delivery requirements, accommodating a wide range of drugs from small molecules to proteins and nucleic acids. Their adaptable design permits the development of multifunctional delivery systems capable of responding to various physiological stimuli. The incorporation of nanofibers into drug delivery systems holds the potential to overcome the constraints of conventional methods, offering more efficient and patient-friendly treatments for diverse medical conditions.

Keywords: Nanofibers, drug delivery systems, pharmaceutical technology

Introduction

The realm of drug delivery systems has undergone remarkable advancements in recent decades, spurred by the imperative to enhance therapeutic efficacy and patient adherence while mitigating adverse effects. Among the diverse array of strategies investigated, nanotechnology has emerged as a pioneering frontier. Within this domain, the development of nanofibers for drug delivery applications stands out as particularly promising. Nanofibers, characterized by their high surface area-to-volume ratio, versatile functionalization options, and exceptional mechanical properties, present unprecedented opportunities for precisely controlled and targeted delivery of therapeutic agents. These ultra-fine fibers, typically produced through techniques such as electrospinning, enable precise control over morphology, diameter, and composition, facilitating customization for specific drug delivery needs. Their unique structural attributes facilitate the incorporation of a broad spectrum of drugs, from small molecules to proteins and nucleic acids, ensuring a sustained and controlled release profile crucial for effective treatment regimens. Furthermore, the adaptable design of nanofibrous mats allows for the development of multifunctional delivery systems capable of responding to diverse physiological stimuli. This adaptability not only enhances drug bioavailability and stability but also enables localized and systemic delivery, addressing various medical conditions ranging from chronic wounds to cancer. The integration of nanofibers into drug delivery systems represents an innovative approach that harnesses the synergies between materials science and pharmaceutical technology. This collaboration holds the potential to surmount the limitations of conventional drug delivery methods, offering pathways to more efficient, patient-friendly, and therapeutically effective treatments. As research advances, the ongoing exploration and refinement of nanofiber-based drug delivery systems hold the promise of reshaping the landscape of modern medicine.

Structure of Nanofibers

Nanofibers are distinguished by their ultrafine structure, typically having diameters in the nanometer range. Their morphology is akin to long, slender threads with a high aspect ratio (length-to-diameter ratio). The structure of nanofibers can vary based on the fabrication method and material used. For instance, nanofibers may consist of single or multiple polymer chains arranged in either a linear or branched configuration, leading to diverse structural forms.

1. **Dimension:** Nanofibers have extremely small diameters, generally ranging from a few nanometers to several hundred nanometers.
2. **Porosity:** They often display a high degree of porosity with interconnected nanoscale pores, contributing to their high surface area.
3. **Alignment:** Nanofibers can be either aligned or randomly oriented, affecting properties such as mechanical strength and conductivity.
4. **Intermolecular Arrangement:** Their molecular arrangement can differ based on the fabrication method and material used.

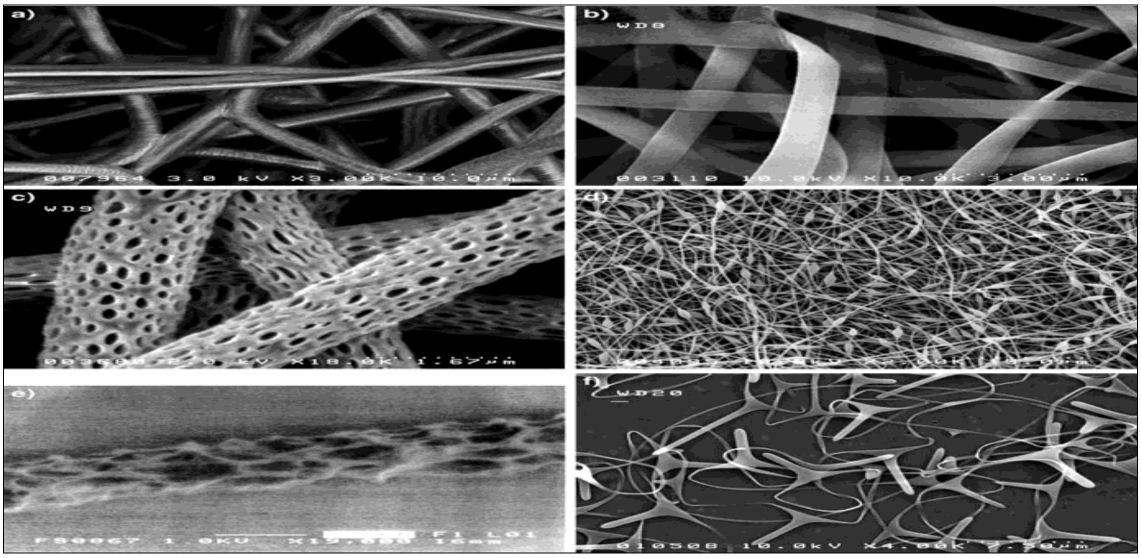

Fig 1: Chemistry of Nanofibers

The chemistry of nanofibers primarily depends on the material composition from which they are fabricated. Nanofibers can be constructed from a wide range of materials, including synthetic polymers, natural polymers, inorganic compounds, and composites. Each material imparts distinct chemical properties to the nanofibers, influencing their mechanical, thermal, and surface characteristics. Additionally, the surface chemistry of nanofibers can be modified through surface functionalization techniques, such as chemical grafting or covalent bonding of functional groups, to impart specific functionalities or enhance biocompatibility.

Types of Nanofibers

1. Synthetic Polymer Nanofibers: Polymeric nanofibers are among the most extensively studied and commonly used nanofibers for various applications. Examples of synthetic polymers used for nanofiber fabrication include polyethylene oxide (PEO), polyvinyl alcohol (PVA), polycaprolactone (PCL), poly (lactic-co-glycolic acid) (PLGA), and polyurethane (PU). These nanofibers offer excellent mechanical properties, tunable degradation rates, and versatility in drug encapsulation and release.

2. Natural Polymer Nanofibers: Nanofibers can also be derived from natural polymers such as collagen, chitosan, cellulose, and silk fibroin. Natural polymer nanofibers often exhibit superior biocompatibility and bioactivity, making them suitable for tissue engineering, wound healing, and drug delivery applications. These nanofibers may undergo enzymatic degradation, mimicking the natural extracellular matrix environment, and promoting cell adhesion, proliferation, and tissue regeneration.

3. Inorganic Nanofibers: Inorganic nanofibers, composed of materials such as silica, carbon nanotubes, metal oxides, and metallic nanoparticles, offer unique properties such as high mechanical strength, electrical conductivity, and thermal stability. These nanofibers find applications in electronics, catalysis, filtration, and sensing, in addition to drug delivery and biomedical applications.

4. Composite Nanofibers: Composite nanofibers combine two or more materials, typically a polymer matrix reinforced with nanoparticles or nanofillers. The incorporation of nanofillers such as graphene, carbon nanotubes, or ceramic nanoparticles enhances mechanical strength, electrical conductivity, and other functional properties of the nanofibers. Composite nanofibers exhibit synergistic effects, offering tailored properties suitable for a wide range of applications, including tissue engineering, drug delivery, and environmental remediation.

(a) Based on Composition

Polymer Nanofibers: Synthetic Polymers: Derived from synthetic materials like polyesters, polyamides, and polycarbonates. They are widely used due to their versatility, flexibility, and tenable properties.

Natural Polymers: Derived from natural sources like proteins (e.g., collagen), polysaccharides (e.g., chitosan), or DNA. They often exhibit biocompatibility and are suitable for biomedical applications.

Carbon-Based Nanofibers: Carbon Nanotubes (CNTs): Hollow cylinders of carbon atoms with exceptional mechanical, electrical, and thermal properties.

Graphene Oxide Nanofibers: Produced from graphene oxide sheets, offering high surface area and potential in various applications, including energy storage and sensing.

Ceramic Nanofibers: Oxide Nanofibers: Composed of metal oxides like titanium oxide, aluminium oxide, or silica. They possess high-temperature stability and mechanical strength.

(b) Based on Fabrication Methods

Electro spun Nanofibers: Electro spun Polymer Nanofibers: Produced using electrospinning techniques, allowing precise control over fibre diameters and structures.

Coaxial Electrospinning: Involves spinning two different polymers or materials simultaneously, creating core-shell structured nanofibers.

Template-Synthesized Nanofibers: Fabricated using templates to control the size and structure of the resulting fibres. Porous templates or sacrificial materials guide the nanofiber formation.

Self-Assembled Nanofibers: Created through self-assembly processes of peptides or other organic molecules, forming fibrous structures.

Based on Applications

Biomedical Nanofibers: Tissue Engineering Scaffolds: Designed to mimic natural extracellular matrices for cell growth and tissue regeneration.

Drug Delivery Nanofibers: Engineered for controlled release and targeted delivery of pharmaceutics
Filtration Nanofibers: Air and Water Filtration: Utilized for their high surface area and fine pore structures, trapping particles and pollutants

Electronic Nanofibers: Conductive Nanofibers: Used in flexible electronics, sensors, and batteries due to their excellent electrical properties.

Textile Nanofibers: Functional Textiles: Nanofiber-enhanced fabrics with properties like breathability, durability, and moisture-wicking.

Properties of nanofibers

- Nanofibers possess unique properties due to their small size and high surface area-to-volume ratio, making them valuable across various fields.
- Their high surface area enhances reactivity, making them ideal for catalysis, sensors, and adsorption. Despite their small size, nanofibers exhibit remarkable strength, especially when aligned, finding applications in reinforcing materials and lightweight composites.
- They are highly flexible, enabling use in flexible electronics and tissue engineering, and their porous structure facilitates filtration applications. Certain nanofibers exhibit optical transparency and electrical conductivity, suitable for transparent electrodes and electronic devices.
- Biopolymer-based nanofibers are biocompatible and can mimic natural tissues, making them useful in biomedical applications like tissue engineering.
- Nanofibers also offer thermal and chemical stability, allowing for applications in high-temperature environments and chemical-resistant materials.
- Harnessing these properties enables tailored applications across biomedicine, materials science, electronics, and environmental engineering.

Advantages

- Nanofibers demonstrate healing effects and biomedical applications, such as bone regeneration and anti-inflammatory effects on intestinal cells.
- They enhance absorption in enterocytes and show potential in animal nutrition, with pupunha palm heart nanofibers increasing rat body weight by 9% without toxicity or histopathological changes.
- Cellulose nanofibers reduce lipid digestion and absorption, improving blood lipid profiles. Nano minerals, including selenium, zinc, and chromium, have growth-promoting and immunomodulatory effects, enhancing weight gain, egg production, and product quality in poultry diets.

Disadvantages

- Current technologies for large-scale fiber preparation need improvement for robustness, particularly in energy generation and storage, where lab-stage achievements in nanofibers with high efficiency and density require solutions for mass production challenges.
- In environmental sensing and governance, achieving complex functions such as filtration, sensing, catalysis, and reusability warrants further exploration.
- The future trend lies in smart wearable devices, where integrating nanofibers with electronic devices for health detection, early warning, diagnosis, and treatment shows promising development.
- Achieving compatibility of nanofiber production methods with traditional industries, such as textiles, faces challenges due to nanofibers' small size and fragility. Innovations are needed for effective fusion and utilization of different nanofibers.
- Identifying "killer" applications of nanofibers is crucial to demonstrate the core value of this technology.

In-vitro evaluation

In vitro evaluation of nanofibers involves studying their properties and behavior in controlled laboratory settings rather than within living organisms. This approach allows researchers to assess various characteristics of nanofibers, including their mechanical, chemical, and biological properties. Common aspects of *in vitro* evaluation include examining nanofiber morphology, assessing mechanical strength and flexibility, studying interactions with cells and proteins, and evaluating their potential for drug delivery. Techniques such as scanning electron microscopy (SEM), atomic force microscopy (AFM), and cell culture assays are often employed to gather data on nanofiber performance. *In vitro* studies play a crucial role in understanding nanofiber behavior and guiding their development for a wide range of applications, from tissue engineering to filtration systems and beyond.

Mechanical properties

Nanofibers exhibit unique mechanical properties due to their small size and high surface area-to-volume ratio. Key mechanical properties of nanofibers include high strength, with exceptional tensile strength making them much stronger than their macroscale counterparts, attributed to their small cross-sectional area and the inherent strength of the materials used in their production. They are highly flexible, allowing them to bend and deform without breaking, which is advantageous in applications like textiles and flexible electronics. Nanofibers can also be highly elastic, returning to their original shape after deformation, crucial for applications involving repeated bending or stretching. Depending on the material used, nanofibers can exhibit a high degree of stiffness, with some being as stiff as traditional engineering materials like steel, while others are more flexible. They can be tough, capable of absorbing significant energy before breaking, which is important for applications requiring impact resistance. Additionally, due to their small size, nanofibers can resist buckling under compressive loads, advantageous in structural applications.

Chemical composition

The chemical composition of nanofibers can vary widely depending on the specific material and manufacturing process used. Common types of nanofibers include polymeric nanofibers, which are made from various synthetic or natural polymers such as polyethylene, polypropylene, polyacrylonitrile, polylactic acid (PLA), polyvinyl alcohol (PVA), cellulose, nylon (polyamide), and polycaprolactone (PCL). Carbon nanofibers, composed mainly of carbon, include types such as carbon nanotubes (CNTs) and graphene nanofibers. Ceramic nanofibers are typically made from inorganic materials like silica (SiO_2), alumina (Al_2O_3), titanium dioxide (TiO_2), and zirconia (ZrO_2). Metallic nanofibers are made from metals or metal alloys, including gold (Au), silver (Ag), copper (Cu), nickel (Ni), and titanium (Ti). Composite nanofibers are created by combining two or more materials to achieve specific properties, such as polymer/carbon nanotube composites. Biodegradable nanofibers are often made from biodegradable polymers like PLA, PCL, or chitosan, which can naturally break down over time.

Biocompatibility of nanofibers

Biocompatibility refers to the ability of a material to interact favourably with biological systems without causing harm or adverse reactions. Nanofibers, with their unique properties and tunable characteristics, offer several advantages in terms of biocompatibility. Their exceptionally high surface area-to-volume ratio allows for better interactions with biological entities such as cells and proteins, promoting biocompatibility. Nanofibers can be engineered to mimic the structure and composition of the body's natural extracellular matrix (ECM), facilitating cell adhesion, proliferation, and tissue regeneration. They can be made from a wide range of biocompatible materials, including natural polymers like collagen and synthetic polymers like PLA, allowing for the selection of materials well-tolerated by the body. Nanofibers can encapsulate and control the release of bioactive agents, such as drugs or growth factors, aiding in tissue repair and regeneration. Often used as scaffolds in tissue engineering, their porous and fibrous structure supports cell growth, enabling the creation of artificial tissues and organs. Well-designed nanofibers can minimize the body's inflammatory response, reducing the risk of rejection or adverse reactions in medical implants or drug delivery systems. They can be engineered to have mechanical properties similar to various tissues, making them suitable for applications ranging from flexible implants to rigid bone substitutes. The effect of nanofibers on cell viability and proliferation can be assessed using various cell culture assays, like the MTT or Alamar Blue assay, to determine if they support or hinder cell growth. Examining how cells adhere to nanofiber scaffolds and their morphology on the fibers provides insights into their biocompatibility and suitability as cell scaffolds. Cytocompatibility is evaluated by studying the impact on cellular functions, such as cell metabolism, gene expression, and differentiation. If used for drug delivery, the ability of nanofibers to release drugs or bioactive molecules in a controlled manner and their effect on target cells are tested.

In-vivo evaluation

In order to evaluate the safety, effectiveness, and biocompatibility of nanofibers for a range of biomedical and therapeutic applications, *in vivo* evaluation entails examining the behavior and performance of nanofibers within living beings, usually using animal models. Examining the interactions of nanofibers with living tissues and organs, as well as the local tissue response, inflammation, and immunological responses following implantation, are typical *in vivo* evaluation techniques. The capacity of nanofiber scaffolds to support tissue regeneration and repair, as well as their integration with host tissue, is assessed if they are employed in tissue engineering. If the nanofibers are intended to biodegrade, then the rate of decomposition and the evaluation of byproducts in the biological system are tracked. The degree of inflammation and foreign body response to nanofibers over time is also evaluated. Examining the interactions of nanofibers with living tissues and organs, as well as the local tissue response, inflammation, and immunological responses following implantation, are typical *in vivo* evaluation techniques. The capacity of nanofiber scaffolds to support tissue regeneration and repair, as well as their integration with host tissue, is assessed if they are employed in tissue engineering. If the nanofibers are intended to biodegrade, then the rate of decomposition and the evaluation of byproducts in the biological system are tracked. The degree of inflammation and foreign body response to nanofibers over time is also evaluated. Pharmacokinetics of drugs or molecules released from nanofibers, including their distribution, metabolism, and elimination in the body, are studied. The mechanical compatibility of nanofibers with specific tissues, such as the mechanical stability of nanofiber implants in bone or soft tissue, is evaluated. Long-term durability and performance of nanofibers within the living system are examined to ensure they maintain their intended function over time. Histological analysis is conducted to study structural changes in tissues surrounding or interacting with nanofibers, including examining tissue sections under a microscope. *In vivo* evaluations are crucial for understanding how nanofibers perform in complex biological environments and whether they meet the safety and efficacy requirements for clinical applications. These studies bridge the gap between laboratory-based *in vitro* assessments and potential clinical trials, ensuring the translation of nanofiber-based therapies and implants into practical medical use.

Conclusion

Nanofibers offer a promising avenue in drug delivery systems, providing unmatched opportunities for precise and targeted administration of therapeutic substances. Their distinctive characteristics, such as high surface area, mechanical flexibility, and adaptability, allow for tailored solutions to various medical requirements. Although challenges persist, like achieving large-scale production and integration into traditional industries, ongoing research and innovation hold the promise of transforming modern medicine. As advancements in nanofiber-based drug delivery systems progress, they stand ready to revolutionize pharmaceutical technology, offering more efficient, patient-friendly, and potent treatments for diverse diseases and conditions.

References

1. Nalwa HS. Handbook of nanostructured materials and nanotechnology. San Diego: Academic Press; c2000.
2. KO FK, Wan Y. Introduction to Nanofiber Materials. United Kingdom: Cambridge University Press; c2014.
3. Laurencin CT, Nair LS. Polyphosphazene Nanofibers for Biomedical Applications: Preliminary studies. In: Laurencin CT, Nair LS, eds. Nanoengineered Nanofibrous Materials Series: NATO Science Series II, Mathematics, Physics and Chemistry; c2004. p. 283-302.
4. Krupk R, Hennrich F, Löhneysen HV, Kappes MM. Separation of Metallic from Semiconducting Single Walled Carbon Tubes. Science. 2003;301(5631):344-347.
5. Ramakrishna S, Fujihara K, Teo W-E, Lim T-C, Ma Z. An introduction to electrospinning and nanofibers. USA: World Scientific Publishing Co. Pte. Ltd; 2015.
6. Hagewood JF. Polymeric Nanofibers – Fantasy or Future? Tech Textile Tech; c2002, 1(1).
7. Hegde RR, Dahiya A, Kamath MG. Bicomponent Fibers; c2006 May. Available from: http://www.engr.utk.edu/mse/pages/Textiles/Bicomponent%20fibers.htm.
8. Fitzgerald WE, Knudsen JP. Mixed-stream spinning of bicomponent fibres. Textile Res J. 1967;37(6):447-453.
9. Lewin M, Sello SB. Handbook of Fiber Science and Technology. New York: M. Dekker; c1985.
10. Nakata K, Fujii K, Ohkoshi Y, Gotoh Y, Nagura M, Numata M, Kamiyama M. Poly (ethylene terephthalate) nanofibers made by sea-island type conjugated melt spinning and laser-heated flow drawing. Macromol Rapid Commun. 2007;28(6):792-795.
11. Ma PX, Zhang R. Synthetic nano-scale fibrous extracellular matrix. J Biomed Mater Res. 1999;46(1):60-72.
12. Yang HF, Yan Y, Liu Y. A Simple melt impregnation method to synthesize ordered mesoporous carbon and carbon nanofiber bundles with graphitized structure from pitches. J Phys Chem B. 2004;108(45):17320-17328.
13. Li X, Tian S, Ping Y, Kim DH, Knoll W. One-step route to the fabrication of highly porous polyaniline nanofiber films by using PS-b-PVP deblock copolymers as templates. Langmuir. 2005;21(3):9393-9397.