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Review Article

Application of Nano Fibre Composites in Drug Delivery – A Review of The Recent Advances

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Abstract

A medication's approximate release profile should be sustained in order to generate the desired therapeutic effect. The drug's release site, duration, and rate must all be adjusted to the drug's therapeutic aim. However, when designing drug delivery systems, this may be a considerable hurdle. Electro spinning is a promising method of creating a nanofibrous membrane since it enables drugs to be placed in the nano fiber composite and released over time. Nano fiber composites designed through electro spinning for drug release purposes are commonly constructed of simple structures. This nano fiber composite produces matrices with nano scale fiber structure, large surface area to volume ratio, and a high porosity with small pore size. The nano fiber composite's large surface area to volume ratio can aid with cell binding and multiplication, drug loading, and mass transfer processes. The nano fiber composite acts as a container for drugs that can be customized to a wide range of drug release kinetics. Drugs may be electrospun after being dissolved or dispersed in the polymer solution, or they can be physically or chemically bound to the nanofiber surface. The composition and internal structure of the nanofibers are crucial for medicine release patterns.

Kew Words: electrospinning; nanofiber; drug delivery; drug release; nanofiber composite

Introduction

Nano structured materials, also known as nanomaterials, are becoming more common in our daily lives and are considered as the trendiest basic materials. Nanomaterials also offer incredible promises for enhancing the performance of existing materials while at the same time introducing new features and uses. Nanomaterials have sparked tremendous interest in research and industrial applications during the last few decades. Nanomaterials, defined by their size within the nanoscale, usually 1 to 100 nm, are of significant interest due to their limitless potential application in the health care area [1]. Nanomaterials have gained a lot of interest due to their distinct features such as a huge surface area and designed properties such as high porosity [2]. At the nanoscale, these nanoparticles offer a number of ways to combine materials in new ways by taking advantage of the unique way these materials interact with each other. [2]. Numerous studies have been conducted using biomaterials with a definite 3D structure and cell-informative signals with components similar to the extracellular matrix (ECM) to control the cycles' biological activity [3–5]. Many ECM molecules contain a diversity of intertwined nanoscale fibrous constructions that promote cell adherence and bioactivity, therefore producing architectural scaffolds that imitate ECM [6]. Nanomaterials are now being researched in various disciplines including self-assembly and thin films, quantum dots, nanofibers, nanorods, nanotubes, nanowires, nanocrystals, and nanofoams [7]. It is widely accepted that nanofibers are one of the most fascinating and significant 1D nanostructures that may be employed in nonwoven membranes.

Scaffolds with a nanofibrous structure have been created via phase separation, self assembly, and electrospinning [8]. Among the processes to produce nanofibrous scaffolds, the electrospinning approach has received much attention from numerous industries. Nanofiber membranes are created using electrospinning, also known as electrostatic spinning. This technique is a unique and basic method that is easy to use, cost-efficient, and has the potential for upscaling, allowing for new industrial applications [9,10]. Recent research and commercial interest in electrospinning, a widely used process for electrostatic fiber production that harnesses electrical forces to make polymer fibers with diameters ranging from 2 nm to several micrometers, has increased dramatically [11,12]. Worldwide research and publications linked to electrospinning have gradually increased over the last

decade. The data in Figure 1 demonstrates that over the past 22 years, the total number of publications in electro spinning have elevated remarkably from only five papers in 2000 to 1880 in July 2022. These data were retrieved from Scopus using the term electro spinning nano fibers and covered a variety of topics including improvements in electrospun functional nanofibers [13–16], electro spinning processing parameters [17,18], and electrospun characterization for a variety of applications [19–22].

Nanofibers excite a lot of interest nowadays due to their outstanding characteristics. Nano fibers are fibers with diameters ranging from 1 to 100 nanometers. Nano fibrous materials are being researched and created because they hold great potential for a wide range of uses while also achieving some of the benefits of nano structured materials. Moreover, the field of nanofibers has piqued the attention of many in the fields of biotechnology and medicine, and it has seen rapid progress in recent years. Nano fibers have beneficial properties such as a large surface area-to-mass ratio, adjustable size, shape, and the capacity to construct a porous mesh, which provides an excellent three-dimensional (3D) network environment, which accounts for their increased capabilities [23]. 3D electro spun scaffolds are also helpful for infusion nutrients and cell penetration into the fiber deepening structure [24]. Significant technological developments in the electro spinning technique have allowed for the development and fabrication of desirable features of novel polymeric materials including the structural modification of nanofibers and their capacity to alter wettability, conductivity, and antimicrobial properties [25].

A medication needs a proper drug delivery mechanism to produce the requisite therapeutic effect to ensure its specific release profile. As precisely as feasible, the disposition, time, and release rate of a medication must be adapted to the therapeutic goal of the medicine. It is widely utilized to regulate the medication supply from hydrophilic and biodegradable polymers in health care due to the obvious distinctive traits of nanofibers. A wide variety of medicines such as water-insoluble medications, soluble in water drugs, weakly soluble in water drugs, and macromolecules including bioactive proteins and DNA should be supplied with nanofibers [26]. A composite material is a mixture of two or more different materials with distinct physical and chemical characteristics. When the two materials are combined, they form a material that is tougher, or lightweight. The combination can also increase the strength and rigidity. Biocompatibility, biodegradability, excellent specific modulus, and durability are only a few of the benefits offered by fiber-reinforced composite fibers to the biomedical field [27]. A polymer composite is a multi-phase material that combines reinforcing fillers with a polymer matrix to provide synergistic mechanical qualities that neither component could attain alone [28]. Many studies have been conducted considering the employment of nanofiber composite scaffolds in nerve tissue engineering, antimicrobial applications, blood vessel graft, cancer nanomedicine delivery, soft tissue reconstruction, diabetic wound healing, artificial muscled design, and bone regeneration [29–36]. Ergo, this review article has emphasized the significant ability of electro spinning and post-treatment modification to produce nanofiber composites as drug carriers in drug delivery applications. First, a brief overview emphasizes the electrospinning technique as an approach to fabricate nanofibrous scaffolds for drug delivery purposes. Parameters affecting the fabrication of nanofibers, synthetic and natural polymer nanofiber, nanofiber system type, and drug release mechanism are also topics that are discussed in this review. In addition, this review also highlights the benefits and drawbacks of each material, type, the properties, and characterization approaches of the nanofiber composites utilized in the manufacturing of nanofiber composite scaffolds. Moreover, this review accentuated the latest application of electrospun nanofibers as drug carriers in pharmaceuticals, bone tissue engineering, nerve tissue engineering, periodontal tissue engineering, wound dressing, and cancer therapeutics drug delivery.

Electrospun Nanofiber

Electrospinning is a technique that employs nanoscale fibers to construct an impermeable nonwoven fabric by driving a liquid jet with a millimeter diameter through an electric field-induced nozzle, which results in the formation of submicron fibers. Generally, electrospinning is an electrohydrodynamic technique.

The following aspects are considered

2.1. Nanofiber for Drug Delivery

2.2. Types of Nanofiber Composite Used in Drug Delivery

2.3. Characteristics of the Nanofiber Composite

The Use of Nanofiber Composite as a Drug Delivery System

A growing number of researchers are interested in the unusual physiochemical features such as the huge surface area, smaller diameter, and high aspect ratio of the composite nanofibers made from biodegradable and biocompatible polymers [37–40]. An electrospun nanofiber that meets these criteria is ideal for use as a drug carrier. Composite nanofibers refer to multiphase fiber structures in which minimally, one of the phases has a dimension in the nanoscale. Primarily, the mechanical characteristics, heat resistance, chemical stability, surface and optical properties, electrical conductivity, and molecular permeability of the composite nanofibers outperformed those of the separate material components in a variety of areas. The potential of electrospun nanofibers being incorporated with a composite to enhance the properties can be seen in a study conducted by Rezk et al., who incorporated beta-tricalcium phosphate into polycaprolactone and cellulose acetate to form a composite mat to imitate apatite to stimulate the biomineralization process [41]. They also loaded simvastatin into a multi-membrane of polyvinyl alcohol and polyvinyl acetate to promote and enhance the osteogenic process with the use of controlled drug release [42]. Li et al. [43] successfully fabricated a compound nanofiber made of flexible inorganic composites with carboxy modification for sustained drug release.

This study revealed that a greater amount of drug loading capacity, and a slower drug release rate were achieved once these nanofibers were further treated with carboxyl radicals [44]. The ionic contact involving daunorubicin molecules and the carboxyl group, which has been confirmed by FTIR, was the primary mechanism of the improved drug loading. Abasalta et al. [45] performed a coaxial electrospinning method to produce core shell. nanofibers composed of an N-carboxymethyl chitosan-polyvinyl alcohol/polycaprolactone composite loaded doxorubicin, an anticancer drug. The incorporation of N-carboxymethyl chitosan into the polyvinyl alcohol solution was then electrospun together separately with polycaprolactone through the coaxial electrospinning setup [46]. In contrast to physiological pH, the carboxylic and amine groups of N-carboxymethyl chitosan were shown to be weak at a pH of 5.5, resulting in greater swelling and quicker release of doxorubicin from the nanofibers at acidic pH. Doxorubicin molecules were more easily dispersed from the nanofibrous matrix at acidic pH because of the increased solubility of doxorubicin at acidic pH. Consequently, the composite nanofibers that were constructed from the core-shell matrix are ideal candidates for use as a pH-sensitive drug carrier for doxorubicin. Zhao et al. [47] successfully constructed a drug delivery system from a composite nanofiber made of carboxymethylation curdlan incorporated polyethylene oxide through the electrospinning process. In their research, the presence of carboxymethylation curdlan in polyethylene oxide can increase the conductivity of the spinning solution, which was due to the enhanced ionization properties of carboxymethylation curdlan. The elongation of the nanofibers dropped notably when the carboxymethylation curdlan concentration in the nanofibers was increased. The presence of hydrogen bond interactions between the carboxymethylation curdlan and polyethylene oxide in the nanofibers resulted in the tensile strength and Young's modulus being notably escalated as the carboxymethylation curdlan concentration increased.

The following aspects have been considered

3.1. Applications in Pharmaceuticals

3.2. Tissue Engineering

3.2.1. Bone Tissue Engineering

3.2.2. Nerve Tissue Engineering

3.2.3. Periodontal Tissue Engineering

3.2.3. Periodontal Tissue Engineering

3.3. Wound Dressing

3.4. Cancer Therapeutics Drug Delivery System

Future Perspectives

Composite nanofiber architectures have aided in the evolution of drug delivery applications by allowing for the regulated delivery of therapeutic agents in consistent dosages over extended periods of time, cyclic dosing, and the infinitely adjustable release of both hydrophilic and hydrophobic medicines. Current drug delivery developments are now based on a fundamental construction of polymers that are suited for particular contents and are made to perform diverse biological activities. Optimizing a composite with a polymer as electrospun nanofibers to form a drug carrier to deliver the medications to a specific location is extremely crucial in drug delivery applications, tissue engineering, cancer treatment, and pharmaceutical applications. Future work may further focus on the development of a smart drug delivery system that is sensitive to optical stimulation, pressure stimulation, electric impulses, ultrasound exposure, or electromagnetism in order to provide targeted drug administration. Additionally, the fast growth of knowledge and the creation of more advanced mutual systems could help make it easier to make smart, integrated devices that can control the amount of drug released from the nanofibrous membrane when the body is stimulated. On the other hand, second phase nanomaterials, which are also known as filler materials, possess appealing characteristics such as high surface area in the nanoscale, and great biocompatibility, which produces a good drug carrier. Therefore, more research using second phase materials with natural polymers such as gum arabic, chitin, honey, pectin, wool, starch, dextran, and chitosan is needed for a controlled and targeted drug delivery system.

Conclusions

Over the last few decades, electrospinning has changed significantly. Electrospinning is a quick and easy way to make drug delivery systems that are smart and can be controlled. Electrospinning can be used in many different ways, and it is a great place to start when making new ways to deliver drugs that improve therapy while reducing the side effects. The choice of drugs and polymers can easily be adjusted for different uses or areas. By changing the mechanical properties or release kinetics, the nanofiber could lead to new ways to make precise medications. Amongst the most complex and challenging obstacles in medication delivery is getting the intended therapeutic agent to the right place at the right time with the right dosage. In this review paper, we highlighted the utilization of nanofibers as drug loaders or drug carriers for controlled drug release. The design of nanofibers is essential for drug delivery purposes, which in this review paper, we emphasized the categories of nanofiber composites being used in a drug delivery system. Characteristics of the nanofiber composites are highly customizable to specific purposes and applications. Nanofibrous scaffolds are an area of research that has not been fully explored yet in diabetes, hormone treatment, and immune disorders. The problems with electrospun nanofibers might be easier to solve with a thorough and structured plan. Enhanced scaffolds that incorporate tissue engineering with controlled drug release without negative side effects could be a useful tool in the future for treating patients in hospitals. Configurable nanofibers could play a pivotal role in personalized medicine because of their unique properties and ease of use.

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