

Review Article

Basic Principles of Electrospinning, Mechanisms, Nanofibre Production, and Anticancer Drug Delivery

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Electrospun nanofibres are environmentally friendly compounds, when compared with other approaches of manufacturing nanofibres. This study reviews an easy and simple approach process of producing nanofibres called electrospinning. This review further gives an overview and successful methodical approaches to obtain electrospun (ES) nanofibres appropriate for anticancer drug delivery. The properties and characterization of electrospun nanofibres were reported to confirm successful nanofibre production. The application of characterized ES nanofibres is to deliver the anticancer drug to the right target in the human body. The implication of this study is the application of some of the merits of ES nanofibres (biocompatibility, biodegradability, low-cost production, small pore size, and ability to transport anticancer drug to the target cell or organ) to overcome the challenges experienced in the use of anticancer chemotherapeutic agents.

1. Introduction

Restrictions of conventional therapeutic drugs, such as discomfort, incompatibility of blood circulation duration with the human biological system, insolubility, pain, and poor bio-distribution, require the significance of developing new therapeutics for treating various diseases, such as bacteria, cancer, cardiovascular, and inflammatory [1]. Nanomaterials' extraordinary structural potentials have grown significance as promising materials for the development of new therapeutics. Nanofibres with extraordinary potentials have grown significant attention in the field of health care and biomedical research [1]. This study is further aimed at providing history, types, and techniques of electrospinning, as well as properties and factors to successful outcome of nanofibres to act as carriers for anticancer drug delivery to reduce the aforementioned conventional therapeutic drugs' challenges.

1.1. Nanofibres, Drug Delivery System (DDS), and History of Electrospinning

1.1.1. Nanofibres and Drug Delivery System. According to Shariar et al. and Wang et al., nanofibres attracted grown attention in drug delivery and other biomedical applications because of their extraordinary potentials [1, 2]. In line with these two groups of researchers, the focus for this study is nanofibre as it applies to anticancer drug delivery. Additionally, because of the challenge of unwelcome toxicity with the use of nanoparticles, the study is aimed at electrospun nanofibres as anticancer drug delivery system [3, 4]. In the early 1970s, the idea of drug delivery system was introduced. A drug delivery system (DDS) involves a design or a device that enables introduction of a therapeutic agent in the human body to enhance its efficacy and safety by regulating the location, duration, and release rate in the body [5]. Other DDSs are

liposomes, micelles, and nanoparticles [5]. The biocompatibilities of some specific polymers used in some liposomes and micelles are yet to be known, while in some nanoparticles, there complex preparation technology and conditions do not permit extended production [5]. Zamani et al. referred hydrogels, liposomes, and micro/nanospheres as conventional forms of drug carriers' methods, while the electrospun nanofibres are able to significantly enhance drug-encapsulation efficacy and reduce the burst release through suitable selection of a drug-polymer-solvent system or electrospinning technique [5]. Similarly and additionally, Contreras-Cáceres et al. stated that drug delivery systems (DDSs) are usually nanostructures that could be loaded with small molecules or macromolecules, which act as vehicles of therapeutic agents in a pharmaceutical administration process, and currently represent one of the most promising challenges in improvements of biomedical research [6]. A great number of nanoformulations, such as dendrimers, liposomes, micelles, nanoemulsions, Pickering emulsions, and polymeric nanoparticles (NPs), are DDSs applied in the chemotherapeutic treatment of solid tumors [6]. Such materials, as DDSs have abilities to transport a chemotherapeutic molecule to a desired site, therefore improve the drug concentration, to be subsequently released in a controlled manner. Controlled release systems offer some advantages when compared to conventional drug therapies, such as drug sustenance in the blood's desired therapeutic range and the localized drug delivery to a specific target in the human body. In this manner, enhanced pharmacological properties of free drugs and an increment of the patient compliance with a reduced amount of the needed drug and a decreased frequency of drug administration are guaranteed. However, the nanofibre DDS is aimed at transporting and retaining a satisfactory amount of drug for an adequate duration, and it is also expected to avoid degradation of nonreleased drugs in the human body [5]. In 2002, electrospun nanofibres were used for the first time for DDS, which further developed as an effective approach to provide fast dissolving DDSs [2]. Electrospinning is based on the electrohydrodynamic (EHD) phenomenon [7]. Electrohydrodynamic (EHD) techniques are procedures that use electrostatic forces to fabricate fibres or particles of different shapes with sizes in the few microns to nanorange via an electrically charged fluid jet for drug delivery purposes [5]. While Shadriar et al. stated that, nanofibres are ideal nanomaterials for drug delivery research because spectrum of materials could be selected for nanofibre fabrication along with the strategic release of therapeutic drug, Lipol and Rahman stated that nanofibre production supports green chemistry because they are biodegradable and do not impose or introduce adverse effects in the human body in future [1, 8]. Electrospun nanofibres possess large surface areas to volume ratio, well-regulated surface conformation, good surface modification, multifaceted pore structure, and extraordinary biocompatibility [9]. The nanofibre merits provided by Shadriar et al., Lipol and Rahman, and Chiu et al. explain the therapeutic significance of nanofibres to the human body. Different ways of producing nanofibres are *electrospinning*, high-volume production methods (melt fibrillation, island-in-sea and gas jet techniques), highly precise methods (nanolithography and self-assembly), and interfacial polymerization [10, 11]. On the other hand, these ways with the exception of electrospin-

ning are limited when factors of cost, fibre assembly, restricted material ranges, and production rates are considered [10]. The focus on the use of electrospinning which makes it superior to others is the ease of usage, fastness, high surface area, suitability, high production rate, low cost, small pore size, versatility, and well-known approach to produce mega fine fibres in liquid form either as micron or nanosized scale and [8–10]. The disadvantages are repeatability and beading.

1.1.2. History of Electrospinning. Electrospinning is the traditional method to fabricate nanofibres with various morphologies and is often used for the mass production of nanofibres [1]. Electrospinning is an efficient way to synthesize nanofibre matrix [12]. Electrospinning is a very versatile process whose matrices are used for numerous purposes, such as affinity membranes, air and water treatment filtration processes, biosensors, cell regeneration, cosmetics, *drug delivery systems*, solar cells, textiles, tissue engineering, and wound dressing [12]. In 1745, Bose et al. first described aerosol production via the applied electric potentials to fluids, although it came into existence between 1902 and 1903 and was first patented in the same year when Morton and Cooley made this first discovery, where they patented the first device to spray liquid under the electric charge influence and Kiyohito et al. undertook the fabrication of artificial silk in 1929 [10, 13, 14]. Lord Rayleigh studied the charge amount needed by the fluid to control the drop's surface tension. In 1942, the apparatus was redesigned and patented to the present use today. In the 1940s, 1950s, and 1960s, limited studies were essentially focused on attaining fibres with decreased size, homogeneousness, optimized parameters, and instrument design [14]. In the 1990s, educational institutions eventually took up the electrospinning process, and since then, many studies have been conducted on the versatility of fabricating and applying electrospun particles [14]. Bhattarai et al. defined electrospinning as an electrostatic spinning which has been extensively used for over thirty years till now in the fields of science and technology, while Subbiah et al. defined electrospinning as spinning fibres with the assistance of electrostatic forces [14, 15]. The electrospinning process is easy with light equipment. However, the processing parameters and solution parameters influence the homogeneousness, morphology, and porosity of the fibres [14]. The modified parameter in one polymer yields an entirely different result with another polymer, and the fabricated fibres are the combined effects of numerous parameters [14]. Bhattaria et al., further stated that, in addition to the process and solution parameters, the type of electrospinning process has significant influence on fibre fabrication [14]. As a result, they stated that two main aspects to deal with in electrospinning type are solution vs. melt electrospinning and nozzle configuration but later added collector modification as the third. They further gave five methods of incorporating drugs prior to electrospinning as blending, surface modification, emulsion, multdrug delivery, and multilayer coated [14]. Going by Shadriar et al.'s studies, there are five types of electrospinning, namely, blend electrospinning, coaxial electrospinning, emulsion electrospinning, gas-nanofibre jet electrospinning,

and melt electrospinning [1]. According to Lin, the two approaches in electrospinning are the conventional approach, which involves the use of needle-like nozzle, and needleless electrospinning, which will be the focus of this study, because it is based on simplicity [16].

1.2. Mechanisms of Needle-Like Nozzle Electrospinning Device and Production of Nanofibres. Electrospinning device has three main components, namely, a metallic needle (spinneret), high-voltage power supply, and always in between, attached to the spinneret and a collection plate (a grounded collector). The aspect of its mechanism entails firstly hosting the polymer solution in a syringe. The polymer solution in the syringe is ensured to be air bubble free for precision. A metallic needle is connected to a syringe. A syringe pump regulates the flow rate of the solution when it supplies the metallic needle. A high-voltage power supply (often in the range of 1-30 kV) is applied to a liquid droplet of the polymer solution at the nozzle of the metallic needle in order to create a “Taylor cone” [17]. The droplet becomes electrified and stretched, and the induced charges are uniformly distributed over the surface. Electrostatic repulsion and coulomb forces are the two major types of electrostatic forces of the droplet experiences. The electrostatic repulsion counteracts the surface tension, while the coulomb forces are exerted by the external electric field. The electrified jet will experience stretching and thrashing process to be deposited on the counter-electrode in formation of continuous and uniform nanofibres [17]. These uniform nanofibres with nanometer-scale diameters are collected at a distance on a collector plate. Solvent is evaporated from the polymer solution from the needle to the collector plate. A deposition of the nanofibres can be gathered from the collector. According to Rodoplu and Mutlu and Yang et al., the two nanofibre collector types based on the geometrical arrangements of discharging capillary and collection target are horizontal and vertical collectors [18, 19]. While Shadriar et al. stated the simple plate collectors of cylinder or disc plate collector, Cavo et al. stated horizontal, vertical, and rotating plate collectors, and Bhattarai et al. stated different plate collector designs, such as disc, grids, liquid bath, mesh, parallel bars, pin, rotating cylinder, rotating drum with wire wound on it, and rotating rods for research purposes [1, 7, 14]. The mechanism of electrospinning process to produce nanofibres is shown in Figure 1.

1.3. Needleless Electrospinning. In the 70s, the first needleless electrospinning system was patented, where a ring was used as a spinneret for electronically fibre spinning and also applied as a filter [17, 20]. In 2005, needleless electrospinning device using cylinder or rotating roller was patented to replace the 70s’ patent as spinneret (fibre producer) for collective electrospun nanofibres and was marketed by Elmarco Company and branded as “Nanospider” [17]. In recent times, rotary cone was used as spinneret to produce fibre from needleless electrospinning, while some researchers used magnetic fluid beneath the polymer solution to start needleless electrospinning [17]. Additionally, air was propelled to produce bubbles which help to electro-

spun nanofibres from a liquid surface. In theory, produced multiple jets from an open liquid surface were from electrically improved liquid waves, where extra power, such as rotation of a motor driven roller, forms the “Taylor cones” [17]. Needleless electrospinning can be categorized into rotating and stationary electrospinning [17]. The needleless electrospinning (conventional electrospinning) entails electrospinning of nanofibres straight from an open liquid surface, where many jets formed concurrently from the fibre produce without the control of capillary effect which is normally linked to the needle-like nozzles. This problem can be avoided with the application of magnetic field, where it is used to form the “Taylor cones” of a ferrofluid. Bubble spinnerets, porous spinnerets, rotary cylinder, cone, disk, convex or slot spinnerets, and tip electrospinning of the liquid surface are some of the components of the needleless electrospinning reported by researchers [21].

1.4. Comparison between Needle-Like Nozzle Electrospinning and Needleless Electrospinning. In needle-like nozzle electrospinning, limited production of nanofibres is achieved from a single jet of a single needle. In the case of a multiple-needle electrospinning to accomplish high production rate, the process is technologically tiresome due to the difficulty and elevated possibility of clogging (congestion). The challenges observed in needle electrospun nanofibres in wide applications are caused by insufficient economic means to maximize production from the electrospinning process [16]. The recent needleless electrospinning can bring solution to limited mass production and problem of needle clogging experienced by production of nanofibres on large scales [17, 20].

2. Factors Affecting the Successful Outcome of Electrospinning

The main factors affecting the successful outcome of electrospinning are concentration of polymer solution, electrospinning process, evaporation rate, flow rate, nature of polymer, polymer solution type, rheology and viscosity, and volatility [22]. In line with Moon et al.’s main factors affecting the successful outcome of electrospinning, Maleti et al. categorized surface tension, polymer solubility, viscosity, volatility, solution conductivity, molecular weight, and dielectric effects of the solvent under solution parameters. Voltage, flow rate, collector plate, needle diameter, and distance from the spinneret to collector plate were categorized under process parameters, while humidity, type of atmosphere, pressure, and temperature were categorized under ambient parameters [12]. These factors are looked into.

(i) Solution parameters

(i) Surface tension: polymer charges must be high enough to remove surface tension of the solute in the jet. (ii) Polymer solubility: this affects fibre morphology, and the higher the molecular weight, the less dissolution and longer duration for the polymer’s dissolution. (iii) Viscosity: low viscosity supports formation of smooth but beaded fibres, while increased viscosity supports increase in fibre diameter. (iv) Volatility: high volatility supports solvent evaporation

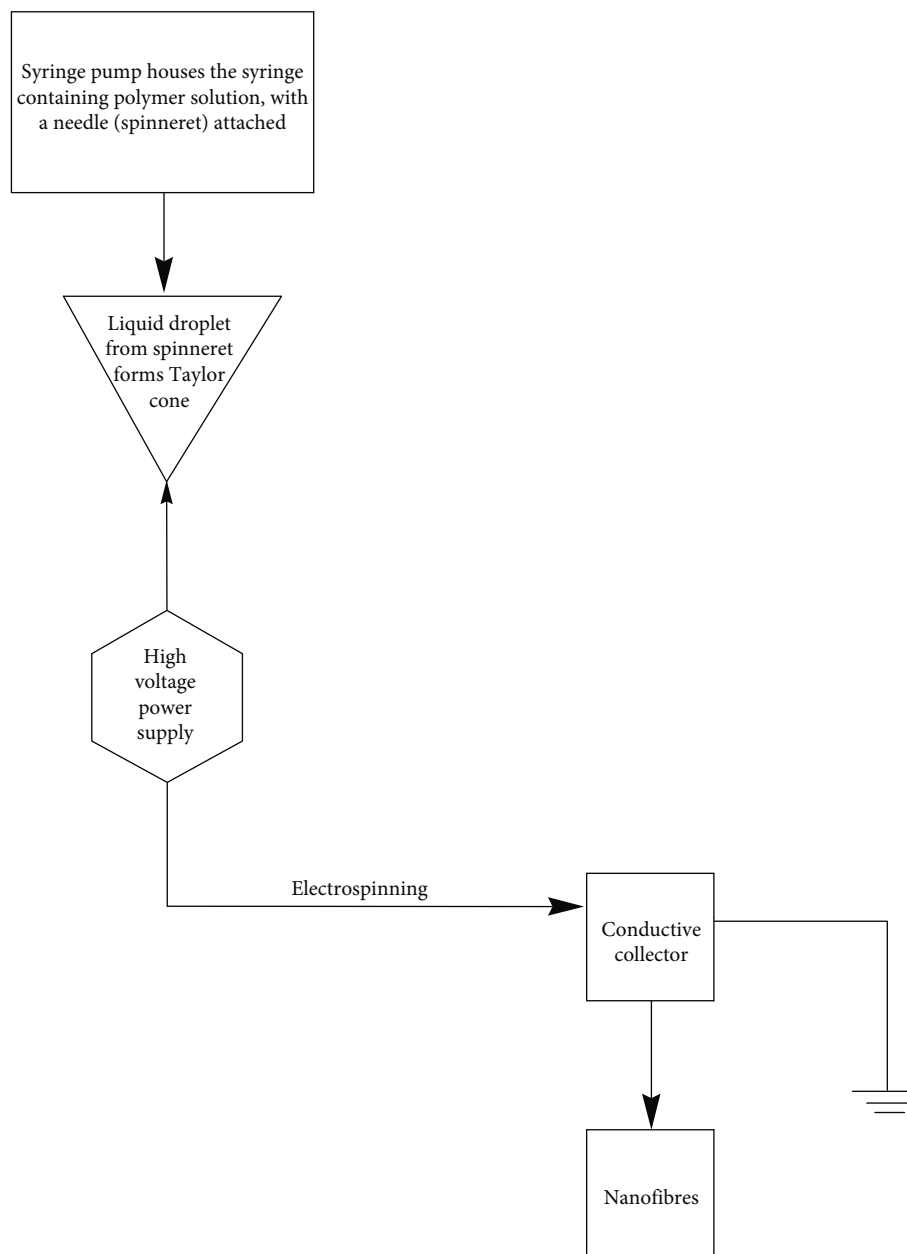


FIGURE 1: Schematic diagram for mechanism of conventional electrospinning process to produce nanofibres.

before the jet reaches the collector, where porous fibres are formed. (v) Solution conductivity: it helps to overcome surface tension, where higher conductivity supports the formation of finer fibres. (vi) Molecular weight: the higher the polymer's molecular weight, the smaller the entanglements and the higher the fibre diameter.

(ii) Concentration of polymer solution and solvent

According to Cavo et al., there are fifty different polymers and solvents that have been successfully electrospun into fibres in the range from 3 nm to 1 mm diameters [7]. Interaction between solvent and polymer is important to ensure a successful nanofibre fabrication. Additionally, the solvent selection influences solution conductivity and fibre

size distribution [7]. It had been reported that the concentration of polymer solution is essential in electrospinning process [16]. A low concentration of polymer solution indicates insufficient chain entanglement which will lead to formation of beaded nanofibres instead of uniform nanofibres, while a high concentration of polymer solution has a high viscosity which hinders stretching of polymer fluid into fine nanofibres. A common challenge when polymer solution, such as polyvinyl alcohol (PVA) and water, is used during electrospinning process is the solution coming out from the tip without pumping any solutions. This challenge can be solved with concentration increase of PVA or a flow rate decrease to obtain homogeneous electrospinning of nanofibres. Variation in the concentration of polymer concentration has little effect on the nanofibre diameter [16].

(iii) Electrospinning process

Haider et al. stated that the amount of voltage supplied, collection plate, distance from the spinneret to collector plate, flow rate of the spinneret and fibre diameter, needle diameter, rate of evaporation of the pure solvent and polymer solution, relative humidity, and temperature affect the process of electrospinning [13]. Mateti et al. explained Haider et al.'s factors, respectively. Higher voltages initiate the electrospinning process, and thick fibres are formed, while lower voltages favor the formation of finer nanofibre fabrication. The collector plate is electrically grounded to certify a safe potential difference between the source and the collector, while nonconductors collect charges on the plane to give fewer fibre deposits. Less distance indicates that the jet travels less distance to reach the collector plate without enough duration to evaporate, therefore forming beads and intrabonding layers, while larger distances agree to more fibre stretching for a decreased fibre diameter. Variance in the rotating speed of spinneret helps to regulate the flow rate in needleless electrospinning in a very restricted range from few revolutions per minutes to 200 revolutions per minutes depending on operating parameters, spinneret dimensions, and spinning solution [23]. A low rotating speed leads to the formation of a thin solution layer on spinneret surface, which cannot be electrospun, while a high rotating speed forms thicker solution layer; thereby, the solution might spill out of the fibre generator surface [16]. The flow rate of the spinneret is proportional to the fibre diameter and the beads' scale; as a result, a slower flow rate is desired for the solvent to evaporate. A limited internal diameter of the needle reduces clogging and the number of beads in electrospun fibres. Rate of evaporation of pure solvent and polymer solution can be determined from the slope of the mass loss curvatures for each solvent [16]. High humidity influences the fibre morphology with water condensation on the fibre surface, where the size and depth of the shaped circular pores are increased. Higher temperature helps decrease the fibre diameter. Other ambient parameters are type of atmosphere, where strong electrostatic fields influence the fibre behaviour and pressure, where lower pressures cause erratic jet formation and solution bubbling at the needle tip because of the direct discharge of electrical charges.

(iv) Nature of polymer

Concentration, cross-linking, isomer structure, and molecular weight affect the nature of polymer [22, 24]. Polymer is the choice for electrospinning because it contains long repeating units [25]. Polymer-based (lactic acid) was the first dependable drug delivery system [26]. Materials used as polymers can be natural (biopolymer and collagen), synthetic (polyacrylonitrile (PAN), polyamide 6 (PA6), polyaniline, and poly(vinyl alcohol) (PVA)), and additives, drug compounds, or plant extracts [25]. Chemical structures of PAN, PA6, polyaniline, and PVA are shown in Figures 2(a)–2(d), respectively. These materials are thermally stable and help the growth of mammalian cells. Other properties are anticancer, antimicrobial, antioxidant, antistatic, barrier properties, conductive, and usefulness as wound dressers, as well as tissue and bone scaffolds.

(v) Polymer solution type

When polymer solution is done under gravity, performance of the downward electrospinning relies on solution properties, such as viscoelasticity and surface tension more than upward rotating electrospinning. [24]. These ideal properties are low surface tension, appropriate charge density, and viscosity to prevent the breakdown of the droplet before solvent evaporation [24].

(vi) Rheology and viscosity

Techniques of rheometry and viscosimetry are used to characterize polymer solution at different shear rates [16]. Instruments used to measure of rheology and viscosity are rheometers and viscometers, respectively. Both instruments have similar principles, but rheometers are more expensive because of their extensive range of uses. Rheological measurements are implemented to access the effect of solution choice on elastic (storage modulus) and viscous (loss modulus) behaviour of the polymer solution. Measurements are carried out in triplicate to avoid error in results. The viscoelastic activities of polymer solutions are significant to electrospinning process and production of electrospun nanofibres. Measurements are also carried out in triplicate to avoid error in results.

3. Properties of Nanofibres

Wang and Hsiao stated that Khan et al. described a fibre as having a diameter in nanometer range; on the other hand, nanofibres were defined as nanomaterial with one dimension less than 100 nm [27]. The smallest nanofibres produced are 1.5 nanometers in diameter. For this study, electrospinning methods used to produce nanofibres with their advantages and disadvantages are shown in Table 1 [28, 29].

3.1. Unique Properties of Nanofibres. Small sizes, large surface area to volume ratio, and mechanical and thermal abilities are the unique physical properties of nanofibres when compared to regular fibres and the bulk polymer [13, 27, 30]. Other unique properties of nanofibres, which are paramount, are their light weights, natural qualities, strength and stabilities. Schematic diagram of the unique physical properties of nanofibres is shown in Figure 3.

- (i) *Small Sizes.* The very small sizes of nanofibres are easily influenced by intramolecular and intermolecular forces (electrical and magnetic forces). These forces enable them to have unique physical and chemical properties, which make them applicable in small places.
- (ii) *Large Surface Area to Volume Ratio.* One of the factors which affect rate of chemical reaction is surface area. The high surface area to volume ratio makes them appropriate for new technologies for maximum applicable therapeutic benefits.

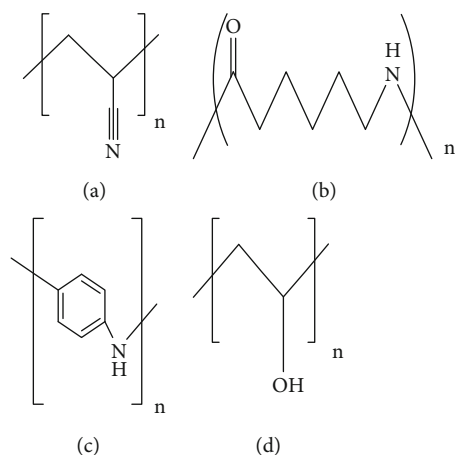


FIGURE 2: Chemical structures of (a) PAN, (b) PA6, (c) polyaniline, and (d). PVA.

TABLE 1: Properties of electrospinning processes.

Manufacturing process	Scope for scaling-up	Repeatability	Control of fibre dimension	Advantages	Disadvantages
Electrospinning (solution)	Yes	Yes	Yes	Long and continuous fibre	Low production
Electrospinning (melt)	Yes	Yes	Yes	Long and continuous fibre	Electric discharge problem

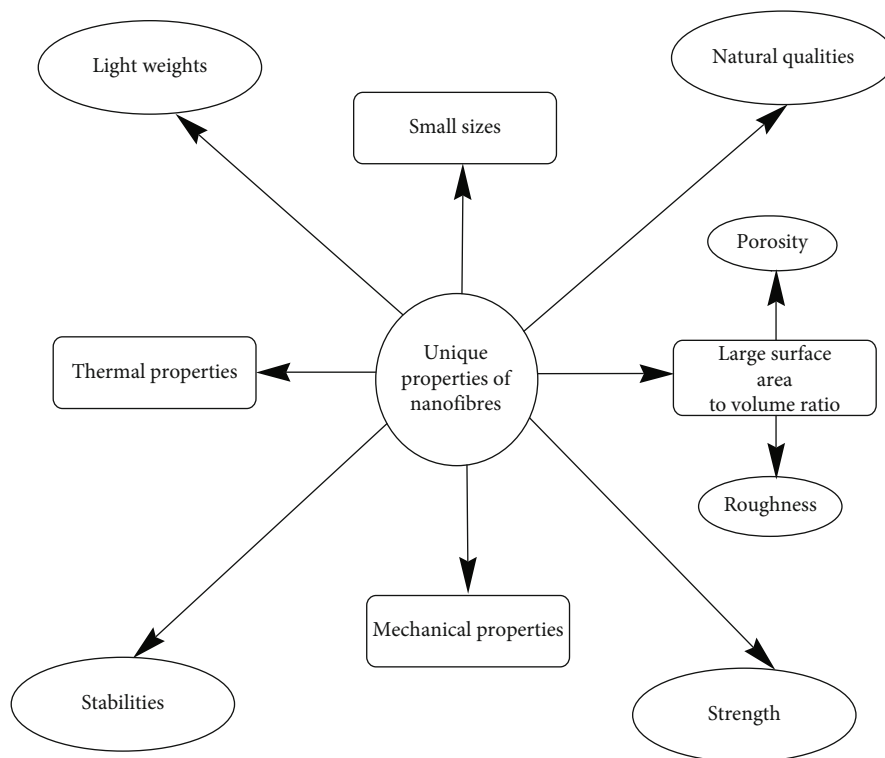


FIGURE 3: Unique physical properties of nanofibres.

(iii) *Mechanical Properties.* The nanostructured surface morphologies of electron fibres have small pores which influence mechanical properties like tensile strength and Young modulus.

(iv) *Thermal Properties.* Thermal properties such as thermal stability of the collected electrospun fibres can be got when thermal analysis is carried on them [13].

3.1.1. Factors which Influence Increased Surface Area. Factors which influence increased surface area are porosity and roughness. Introduction of porosity to nanofibre structure increases the surface area. The different ways of porosity (pores) into the nanofibre structure are rapid phase separation, selective dissolution, selective pyrolyzate composite formation, and thermally induced phase separation. On the other side, roughness of the nanofibre surface leads to increased surface area. Both factors help to improve the application of nanofibres.

3.2. Nanofibre Modification. Nanofibres can be modified and measured. They are modified with copolymerization, plasma, polymer blending, and ultraviolet radiation in order to enhance the capture and prevent the contamination of competing agents for improved membranes [10].

3.3. Sample Preparation and Measurement of the Size of Nanofibres. There is no or less effort needed to prepare samples for Scanning Electron Microscope (SEM analysis). As a result of this, samples can be imaged directly by placing them on aluminium foil. On another note, Transmission Electron Microscope (TEM) needs more efforts in terms of skillfulness of the user, thin and flat nature of samples, and preparation which is artefact free. A general practice for sample preparation is to insert a rectangular nanofibre sheet with a layer such as aluminum foil in a paper sheath and then remove the fibre from the aluminum foil [30]. This insertion and removal processes simply cause fibre damage, where the achieved value is influenced by the overrated value produced because of stress concentration in the neighborhood of the control part during the measurement [30]. The recommended technique for pure and loss (damage)-free samples is to obtain best data in a moment of sample preparation in ion milling [31–33]. Some researchers reported the attractive nature of ion milling to reduce surface damage effects [31]. Alternatively, Kang and Sukigara used compression tester for bulk compression measurement of electrospun nanofibres to avoid loss during the sample preparation [34].

4. Characterization of Nanofibres

Nanofibres can be characterized for their qualitative and quantitative features. This study reports the characterization techniques to obtain both nanofibres' qualitative and quantitative features.

Some of the characterization techniques used are as follows: (i) structural characterization (Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Fourier Transform Infrared Spectroscopy (FT-IR), Atomic Force Microscopy (AFM), Brunauer-Emmett-Teller (BET) adsorption, mercury porosimetry, and Energy Dispersive X-ray Spectroscopy (EDX)), (ii) thermal characterization (Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC)), and (iii) mechanical characterization (contact angle measurement).

4.1. Electron Microscopes. Electron microscopes are potent and valuable implements to characterize extensive range of

materials because of their versatility and very high spatial resolution for numerous applications. Electron microscopy output results from interaction of sample with electron beam. The two main types of electron microscopes are Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). The scale bar tool in the Scanning Electron Microscope (SEM) software can also be used to measure the diameter of number of fibres from different portions of the image and then data analyzed statistically, as well as external morphologies, while the TEM is used to obtain the internal morphologies. In addition, SEM gives a three-dimensional nanostructure image, while TEM gives a two-dimensional nanostructure image.

4.1.1. Scanning Electron Microscope (SEM). Regardless of how nanofibres are produced by melt blown, spun bond, electrospinning, force spinning, or other technology, the imaging and its analyses need better resolution than traditional fibres. Secondary electrons are mainly used for SEM purpose. A SEM is required to measure nanofibre diameter and pore distributions. The collected electrospun nanofibres are coated with gold for them to be visible when set on a slide under SEM and to prevent a repulsive reaction of electron beam [35, 36]. A challenge of SEM is that the experimentation is done under vacuum. On a different note, drying of collected nanofibre is challenging because of vital structural changes of the nanofibre in medicinal applications where polymer materials swell in water environment. This drawback is partially solved by different modifications of SEM, such as Low-Vacuum Scanning Electron Microscopy (LVSEM) [36]. The disadvantage of LVSEM is the lower magnification it has when compared with standard SEM. On the other hand, environmental SEM and AquaSEM methods proceed in aqueous conditions allowing samples to be observed in wet state [36]. The advantages of using SEM to determine nanofibres are the extraordinary sharpness of information it provides about structures at different distances from the scanning level. In summary, SEM is a very useful method to assess the elementary characteristics of electrospun nanofibres, such as fibre diameter, fibre orientation, pore sizes, and pore distributions.

4.1.2. Transmission Electron Microscope (TEM). The Transmission Electron Microscope (TEM) gives a greater spatial resolution when compared with SEM. The TEM's principle uses transmitted electrons as the name suggests. It gives valuable information about the sample's internal structure, morphology, tension, and sample composition, while SEM gives information about the sample's surface and the shape. The incident electron beam diffracts the sample, generating local diffraction intensity deviations which can be transformed into difference to form to form an image in crystalline materials. In the case of amorphous materials, difference is accomplished by deviations in electron scattering as the electrons pass through the sample's chemical and physical contracts.

4.1.3. Atomic Force Microscopy (AFM). Atomic Force Microscopy (AFM) is a powerful instrument of scanning probe microscopy (SPM) which implements its imaging purpose when it measures a surface local property, such as height,

magnetic properties, or optical absorption. It uses a probe or tip which is placed nearby the sample surface to achieve the measurement [34]. Individual tip placements lead to recreation of three-dimensional model of sample surface. The two modes AFM operates are contact mode imaging and noncontact mode imaging [37]. Contact mode imaging uses a soft cantilevered beam with a sharp tip at the end to contact the sample surface. The principal use of contact mode imaging is to produce images of sample topography. Noncontact imaging uses a small diezo element located under the cantilever to enable its oscillate at its reverberation rate. When the oscillating cantilever is lowered within 10-100 nm from the sample surface, interaction forces (capillary, electrostatic, magnetic forces, and Van der Waals forces) between the tip and the sample surface modify the oscillation. In the case of phase shift, it differentiates between surface materials. A disadvantage of noncontact imaging is the ability to retain the correct tip-to-sample distance while avoiding the tip from touching the sample surface. In addition to this, there is tendency for most sample surfaces to develop a liquid meniscus layer in ambient conditions, which makes the task difficult.

(1) *Advantages and Disadvantages of AFM over Electron Microscope.* Advantages of AFM over electron microscope are the production of an accurate three-dimensional surface images, operation in both air and liquid conditions, since it does not need a vacuum environment, production of smaller image sizes than that of electron microscope, slow rate of scanning an image, and the no extraordinary sample treatment is needed, which can lead to variations on sample surfaces [38].

(2) *Application of AFM to Nanofibres.* Apart from the accurate three-dimensional image of sample surface of collected electrospun nanofibres, the AFM also determines the mechanical properties of the nanofibres [39–42]. Nevertheless, this approach requires sophisticated device and competent supervision [39].

4.2. Specific Surface Area and Porosimetry Determination

4.2.1. *Brunauer-Emmett-Teller (BET) Theory.* Characterized results of specific surface area depend on the use of adsorbing gases, such as nitrogen or argon. Lower results are got with bigger molecules [36]. The purpose of Brunauer-Emmett-Teller (BET) theory is to explain gas molecules' physical adsorption on a solid surface. It is also used as a significant analysis technique to measure the specific surface area of materials, such as nanofibres, and observe changes which appear on the edifice in postpreparation modification of organic and inorganic nanofibres. Apart from specific surface area determination, BET measurement reveals pore size distribution up to 10 nm in diameter.

4.2.2. *Adsorption.* Adsorption is another approach to determine the specific surface area of materials, which can be done on a chemical compound got from an organic solvent or isotopically coded compound [43]. Adsorbed compounds are often

extensively bigger to get into smallest pores, which results into lower measured values when compared with BET technique.

4.2.3. *Mercury Porosimetry.* Mercury porosimetry gives mechanical distortion of the nanofibres [36].

4.3. *Chemical Composition of Electrospun Nanofibres and Contact Angle Measurement.* An important quantitative feature in characterization of electrospun nanofibre is the chemical composition. This chemical composition entails the hydrophilic and hydrophobic characteristics of the surface specimen. The best approach to determine the amount of hydrophobicity of the specimen is the use of contact angle measurement. Measurement involves the use of sessile drop or captive bubble method in stationary or kinetic mode. Apart from chemical composition, other factors which have effects on contact angle measurement are heterogeneities and surface structure. Širc et al. reported that cautiousness must be observed with contact angle measurements on nanofibrous materials signifying deformable solids, porous, or swelling in water [36]. Other studies considered to measure the variations in hydrophilicity of the nanofibres after surface modification by contact angle measurement.

4.4. *Thermal Analysis (TA).* Thermal analysis is essential to evaluate the properties and structural relationship of polymeric materials [41]. Thermal analysis is also used to measure the quantity of moisture and volatile compounds in polymer compounds, which might deteriorate the physical and chemical properties depending on crystallization and thermal stability [44]. Thermal analysis used for characterizing electrospun nanofibres can be either Differential Scanning Calometry (DSC) or thermogravimetric analysis (TGA). Both DSC and TGA are used to characterize polymer thermal stability and evaluate the comparative polymer stability of several polymeric materials and the estimation of material lifetimes. The TGA results show stages of thermal breakdown, material weight losses at all levels, degradation degree, degradation nature, and threshold temperature [45]. On the other hand, DSC is used to regulate the phase transition phenomena, glass transition temperature (T_g), polymeric fibres' heat flow, and melting mechanism [44, 46].

4.5. *Fourier Transform Infrared Spectroscopy (FT-IR).* Fourier Transform Infrared Spectroscopy (FTIR) is a nondestructive spectroscopic technique where the infrared light from the spectrophotometer irradiates the electrospun nanofibre to obtain infrared spectrum [27]. The FT-IR is used to distinguish between amorphous and crystalline phases, as well as to study structural changes and chemical bonds in the electrospun nanofibre sample.

4.6. *Energy Dispersive X-Ray Spectroscopy (EDX).* Energy Dispersive X-ray Spectroscopy (EDX) is another spectroscopic technique which reveals the percentage composition of elements present, alongside with impurities [42].

4.7. *Measurement of Diameter, Orientation, and Pore Size (Mesh Hole Size) of Nanofibres.* In order to obtain accurate and valid data from high-resolution microscopic methods,

such as Electron Back Scattered Diffraction (EBSD), Focused Ion Beam (FIB), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM, Cross-Sectional (X) TEM, and High-Resolution (HR) TEM), right measurement is vital. The small diameter of nanofibres, as well as the orientation and pore size (mesh hole size), creates a room to question, "how are they measured?" In most cases, a validated software called ImageJ is used to measure the diameter, orientation, and pore size of nanofibres obtained from SEM images [37]. Data analysis is done using Matlab, Mathematic, or Statistica in order to acquire specific information about average diameter, size distribution, standard deviation, and preparation of suitable graphs. Other yet to be validated softwares to measure nanofibre diameter are edge detection algorithm, radon transforms, and principal component analysis [37]. Mathematical algorithm is used for image analysis to provide extremely enhanced analysis worth of general SEM images [36].

5. Electrospaying during Electrospinning

There have been reported cases of electrospaying during electrospinning.

5.1. Cases of Electrospaying during Electrospinning. During the electrospinning process, the current increase is firstly gradual and then sharply increases from one voltage point to steep increases where electrospaying is observed at the point of a sharp change in current, indicating change or defect in the bead density [14]. Characteristics of fluids, such as low viscosity and viscoelasticity, are also the major differences between electrospinning and electrospay. The fundamental factor responsible for separating electrospaying from electrospinning is the polymer's entanglement density. Major differences between electrospaying and electrospinning are due to some factors [47–49]. These factors and their possible solutions are shown in Table 2. However, according to Bhattaria et al., the distance between the capillary and the plate collector, which plays a significant role in the morphology and size control of the nanofibre needs to be optimized to differentiate between electrospaying and electrospinning [14]. In line with this, a distance ranging from 10 to 20 cm is usually considered to be an effective spinning distance with the electrospinning conventional method [14].

6. Cancer, Anticancer Drugs, and Anticancer Drug Delivery System

6.1. Cancer and Anticancer Drugs. Cancer is a global disease [50, 51]. According to Senapati et al., cancer consists of a variety of diseases caused by uncontrolled growth of malignant cells which can spread to other parts of the human body [52]. Odularu reported a World Health Organization (WHO) estimation of 70% new cancer related cases in the next eighteen years against the 8.8 million cancer cases in 2015, while Li et al. stated a WHO estimation of 22 million cancer related cases in 2035 [50, 53]. Similarly, Senapati et al. stated the WHO estimation of 13.1 million cancer-related cases in 2030 [52]. The commonest cancer diseases are breast, cervical, colon (colorectal), liver, lung, pancreas,

and prostate [6, 12], while contemporary anticancer treatments are surgery, radiation therapy, chemotherapy, or combination of these treatments [26]. They hinder deoxyribonucleic acid (DNA) synthesis and mitosis resulting to death of fast growing and dividing cancer cells [26]. In the case of chemotherapeutic drugs (agents), they are nonselective and are capable of destroying healthy normal tissues, leading to various unwanted side effects, such as appetite loss and nausea. Additionally, the drug's bioaccessibility to cancer tissues is poor; therefore, higher doses are required, resulting to higher toxicity in normal cells and prevalent multiple drug resistance. These challenges are adverse impacts, drawbacks, and multidrug resistance in human systems [21]. In a similar manner, surgeons are facing difficulty in where these anticancer drugs can be inserted in specific regions during their professional practices [8]. These anticancer drugs are either natural or synthetic in nature. The potent natural anticancer drugs that nature has provided us which include anthracyclines (doxorubicin, daunorubicin, epirubicin, and idarubicin), camptothecin (CPT) and its derivatives (hydroxycamptothecin, irinotecan, and topotecan), curcumin (CUR), green tea polyphenols (GTP), quercetin (QUE), taxanes (paclitaxel (PTX)), docetaxel, podophyllotoxin and its derivatives (etoposide (ETP) and teniposide), and vinca alkaloids (vincristine (VCR), vinblastine, vindesine, and vinorelbine), while synthetic anticancer drugs are 1,3-Bis-(2-chloroethyl)-1-nitrosourea, carmustine, cisplatin, 5-fluorouracil (5-FU), dichloroacetate, doxorubicin (DOX), doxorubicin hydroxide, and titanium dichloride [7, 12, 14, 54]. Nevertheless, all electrospun nanofibre-mediated drug delivery approaches for cancer therapy are presently in preclinical and clinical trials [12]. Controlling these challenges might involve upgrading existing anticancer drugs to environmentally benign drugs. As a result, there is an urgency to design new anticancer drugs or improve the existing anticancer drugs to limit the challenges people experienced in cases of water insolubility and poor pharmacokinetics.

6.2. Anticancer Drug Incorporation Techniques, Mode of Administration, and Anticancer Drug Delivery System

6.2.1. Anticancer Drug Incorporation Techniques. During nanofibre electrospun technique, a strong electrostatic field applied to a polymer solution is held in a syringe, and the pendent droplet of the polymer solution is deformed into a Taylor cone [13]. When the electric force overcomes the droplet's surface tension, one or multiple charged jets are ejected from the droplet's tip [6]. As the jet moves to a collector plate, the solvent evaporates, and a nonwoven fabric mat, called nanofibre with nanometers diameter, is formed on the plate. In previous years, this technique was used for various polymers to fabricate biocompatible NF scaffolds, such as biodegradable synthetic polymers (poly(4-vinylpyridine), polyethylene glycol (PEG), PCL(PLGA), PLA, poly(N-isopropylacrylamide (pNIPAM), polyvinyl alcohol (PVA), and polyvinyl pyrrolidone (PVP) [6]. Consequently, the fibre diameter is controlled by various polymer solution properties, such as conductivity, distance between the injector and the metal collector, elasticity, electric field strength,

TABLE 2: Causes of major differences between electrospinning and electrospaying and their solutions.

Cause	Solution
Collector separation causes electric field strength lowering	Process is stopped, and collector could be changed for a new one. Voltage value could also be changed.
Block in needle eye due to solvent evaporation or solute drying	Needle diameter could be changed to a wider gauge. There should be a temperature balance between solution pulling force and evaporation rate. Checking the solution viscosity before electrospinning and after its spraying in order to ascertain temperature activity on solution viscosity
Variations in room conditions, such as temperature or solution varies with time	Stirrer could be used to mix during experimental process. Collection process could be observed during long-time electrospinning process. Non-Newtonian liquids are sensitive to room conditions.
Partial polymer solubilization in the electrospinning solvent causing decreased solution viscosity	Polymer concentration can be increased or polymer solution can be made to stay overnight for solubilization.
Waste fibres' buildup in the electrospinning setup, such as box walls used for electrospinning	Wiping the setup down with some conductive cleaning solution
Separation in polymer solution in case, there is a need for spinning particles with polymer	Getting a stir bar inside the syringe

external parameters (temperature and humidity), polymer concentration, and viscosity [6, 14]. Essentially, these NFs incorporate and acquire chemotherapeutic molecules via two basic approaches of blend and coaxial electrospinnings [6]

- (i) *Blend Electrospinning*. It is based on drug mixing with a polymeric solution before electrospinning process. Blending is the commonest, easy, simple, and main method to incorporate drugs in the polymer solution for drug dissolution before electrospinning [5, 6]. Hence, the physicochemical properties of both drug and polymer are considered to ensure effective homogeneous encapsulation drug distribution in the fibre and pharmacokinetics (drug kinetics release) [5, 6]. In such a scenario, lipophilic anticancer drugs, such as paclitaxel, are dissolved in a lipophilic polymer solutions and hydrophilic anticancer drugs, such as doxorubicin hydrochloride, are dissolved in a hydrophilic polymer solutions for enhanced encapsulation [14]. Improperly dissolved anticancer drug in the polymer solution causes a dispersion which could lead to burst release if the anticancer drug transfers to the fibre surface [14]. To enhance the drug-loading efficacy and to control the burst release, different mixtures of hydrophilic and hydrophobic polymers could be combined and used [14]. However, Mickova et al. compared blending electrospinning of a liposome to coaxial electrospinning and recounted that blend electrospinning could not support intact nanofibres [55]. Additionally, Shahriar stated that despite the blend method's simplicity when compared with other electrospinning methods, the solvents used for bioactive molecule dissolution could result to protein denaturation or biological activity loss [1]. The biomolecule intrinsic charge could also result to their migration on the jet surface, and in this manner results in the surface distribution of the nanofibres rather than the encapsulated anticancer drugs in the nanofibre. The surface distribution could be related to the burst release of the anticancer drug.
- (ii) *Coaxial Electrospinning*. It is based on a concurrent cospinning of two polymeric liquids, involving "core and shell" electrospinning on two needles from two syringe pumps, designed in a coaxial mode [6]. This is a modified version of electrospinning that enables nanofibre fabrication with core-shell morphology and enhances the functionality of biomolecules, where the biomolecule solution formed the inner jet and its coelectrospun with a polymer solution that formed the outer jet [5]. The shell polymer contributes to the continuous release of the therapeutic agent and protects the core constituents from direct contact with the biological environment [5]. This technique has been applied for the paclitaxel (PTX) incorporation into poly(L-lactic acid-co- ϵ -caprolactone), P(LLA-CL) (75:25) NFs to give PTX loaded P(LLA-CL) NFs. The mechanism entails the injector formation by a

coaxial needle where the core (inner part) contains a (PTX) solution and the shell (outer part) contains the polymer [6]. Paclitaxel is a chemotherapeutic drug widely used in bladder, breast, lung, ovarian, and prostate cancer. Nevertheless, recently, main research has focused on the use of synthetic polymers as stimuli-responsive systems, where these structures undergo changes in response to external stimulus, such as ion strength, pH, solvent nature, and temperature. Hence, most recent studies have focused on system formation for drug encapsulation based on two types of polymer types, namely, pH-responsive and thermoresponsive polymers [6].

pH-Responsive Nanofibres. The acidic environment present in the cancer tissues is used to specifically target the anticancer drug release at the cancer site in response to a pH change through the use of nanoformulations sensitive to the pH change [6]. An anionic copolymer, ES100, was instituted by metacrylic acid and methylmethacrylate for pH-responsive nanofibre fabrication for 5-FU delivery research, with coaxial electrospinning, where the core consisted poly(vinylpyrrolidone), ethyl cellulose (EC), and the 5-FU drug, and the shell was pH-responsive ES100 formation. The drug release study revealed that 5-FU diffused through the ES100 polymer pores to produce a controlled drug release established at pH 1, with 80% drug release after 2 h. At that pH, the polymeric fibres were split, to distribute an increased 5-FU delivery.

Thermoresponsive Nanofibres. Generally, there are several conventions to synthesize nanoformulations which are temperature sensitive and are suitable for therapeutics in biomedicine, because they are administered by injection and are biodegradable [6]. Slemming-Adamsen et al. presented an innovative approach to introduce doxorubicin (DOX) into thermoresponsive pNIPAM-NHS/gelatin NFs by a mixture with a solution of pNIPAM-NHS/gelatin acting as a shell with another mixture of EDC (1-ethyl-3-(3-dimethyl-aminopropyl)-1-carbodiimide hydrochloride) and NHS in the presence of DOX [56]. This mixture was electrospun to obtain cross-linked pNIPAM/gelatin NFs containing DOX that can be released in a controlled manner [56]. The DOX-IN-pNIPAM NFs showed thermoresponsive swelling/deswelling properties. Actually, the fabricated cross-linked NFs were able to release DOX with increased temperature.

The main advantage of coaxial electrospinning method over the commonly used electrospinning device is that the fibres are fabricated from two separate solutions, reducing the interaction between aqueous-based biological molecules and the organic solvents in which the polymer is mainly dissolved. However, the main disadvantage of coaxial electrospinning is the design complexity and process electrohydrodynamic (EHD), where the interfacial

tension, spinning parameters, and viscoelasticity of the two polymers must be accurately controlled.

Other drug incorporation approaches are emulsion, surface modification, multiple drug delivery, and multiple layer.

- (iii) *Emulsion*. It is another approach in drug incorporation, where the anticancer drug or the protein solution is emulsified in a polymer solution, where the latter acts as an oil phase, and the electrospinning produces a well-distributed nanofibre of a low molecular weight and a core-shell of a high molecular weight drug [14]. The process success depends on the ratio of the aqueous solution to the polymer solution, which administers the distribution behaviour of the molecule in fibre and also determines the bioactivity of the encapsulated biomolecules, release profile, and structural stability [14]. Although various combinations of hydrophilic drugs and lipophilic polymer could be used, there could be appropriate dissolution of the drug and the polymers to prevent the need of a common solvent [14].
- (iv) *Surface Modification*. Surface modification is the technique in which the therapeutic agent is conjugated to the fibre surface to make it structurally and biochemically similar to the tissue, and the functionality of the biomolecules is protected [87]. This strategy lessens initial burst release and short-term release making it very appropriate for slow and prolong delivery of deoxyribonucleic acid (DNA), enzymes, and gene or growth factors.
- (v) *Multidrug (Combination Therapies) Delivery*. Multidrug (combination therapies) delivery is a current approach where multiple drugs with or without similar therapeutic effects are combined and electrospun with appropriate polymer(s). The most significant feature in multidrug delivery systems is the controlled release of drugs, mainly in cancer or other complex diseases to prevent multidrug resistance. However, independent controlled release of each drug in a multidrug-blended carrier cannot be easily obtained. Different drugs integrated into the same carrier provide the same diffusion pathway and matrix-degradation rate, and hence, the individual drug-release rate cannot be improved. A drug carrier which allows fixing of the release profile of all component drugs is required for realizing a time-programmed multidrug delivery system with a single formulation. In line with this, sequential electrospinning was developed to construct multilayered electrospun mats consisting of various drugs and basement membranes.
- (vi) *Multilayer Coated Nanofibre Technique*. Multilayer coated nanofibre technique is another innovative method of drug incorporation and delivery, which combines electrospun fibres' large surface area with polyelectrolyte multilayer structures to produce

nanofibres. It uses acid-base pairing, electrostatic, or hydrogen bonding in layer-by-layer polymer adsorption for drug delivery applications [14]. In this technique, the fibre size and each layer thickness are active variables in controlling the drug-release rate and timing. A time-programmed, slow drug release is obtained with potential application for successive chemotherapy using multiple anticancer drugs.

6.2.2. Mode of Administration. Drugs/therapeutics can be administered to any region/organ in the body by common routes, such as oral, parenteral (intramuscular, intrathecal, intravenous, and subcutaneous), buccal/sublingual, inhalation, nasal, ocular, rectal, and transdermal.

6.2.3. Anticancer Drug Delivery System. Previously, polymeric nanofibres (NFs) were reported as drug delivery system and scaffolds with abilities to encapsulate antitumor drugs for biomedical research on cancer treatments [14]. Recent reports on the potential cure for cancer tumors are with a range of modern medicine and herbal anticancer drug-loaded electrospun nanofibres [12]. The *in vitro* and *in vivo* trials prove the drug-loaded nanofibres' effectiveness in cancer management [12]. In this situation of right target for anticancer drug delivery, a carrier is needed to grip the drug in the precise place. In cancer treatment, nanofibres have many merits, such as the ability to achieve alignment variation, drug encapsulation, submicrometers to nanometers fibres, and surface modification [7]. Anticancer drug-loaded electrospun (ES) nanofibres support controlled and sustained drug release at the preferred target with enhanced efficacy. The ES nanofibres are used as an implant into a postoperative tumour cavity to inhibit tumour relapse and to extend drug release at the tumour site [7]. A new branch called cancer tissue engineering is aimed at exploring cancer pathogenesis and evolution in a more realistic environment than two-dimensional (2D) cultures or animal models. As a result, the electrospinning technique has been redesigned to obtain three-dimensional (3D) fibrous materials with similar properties to native tumours [7]. In 2014, electrospun matrices gained attention in clinical applications, because of their porous structure and ability of drug incorporation in the fibre lumen. Electrospun fibre matrices are applied as a transdermal drug delivery system (TDDS) to ease delivery via skin in a systematic manner, which is predominantly related to numerous anticancer treatments' drawbacks, such as adverse impacts in healthy tissues, instability in the human body, low concentration at tumour sites, and poor solubility. However, few challenges in electrospun (ES) nanofibre applications are attaining homogeneous drug distribution in ES fibres, drug compatibility in polymer solutions, initial drug burst release, and development of 3D scaffolds with preferred porosity. These few challenges have made all the electrospun nanofibre-based systems for cancer research to still be in preclinical trial stage [7].

6.3. Nanofibre Application as Anticancer Drug Carrier (Drug Delivery). The internal architectures possessed by nanofibres make them better nanocarriers than hydrogels and enable

them to be applied for various applications [57, 58]. Fields where polymeric nanofibres can be applied are biomedical applications, such as catalyst and enzyme carriers, coating, *drug delivery*, energy conversion filtration, nanosensors, and storage, tissue engineering, and wound healing [7, 59]. Numerous successful nanofibres have been obtained from polymers, such as natural, hybrid, and synthetic materials [60]. Drug delivery via polymeric micro/nanostructures is centered on the opinion that an improved surface area of the drug carrier increases the drug-dissolution rate [60]. In reference to Zee-Cheng et al., anticancer drugs are neither particular nor focused to the cancer cells; therefore, enhanced delivery of anticancer drugs to the malignant tumour tissues in humans is a reasonable challenge, which can be attainable [43]. According to Zamani et al., a drug delivery system entails a design which allows introduction of a therapeutic agent into the human body to improve its efficiency and protection by monitoring the drug concentration, position of release, and time in the body [5]. Similarly, Kavayanifar et al. stated that drug delivery systems were advantageous approaches for controlling further execution and benign treatments in genuine situations [61]. This delivery system leads to reduced adverse effects linked with unwanted instabilities in drug concentration or incapability of damaged drug molecules [60, 61]. Chemical methods for the enhancement of drug delivery use prodrugs, biodegradable polymers, and macromolecular matrix techniques [43]. Some commonly used polymers are carboxymethylcellulose, chitosan, collagen, gelatin, and polyvinyl alcohol are combined with fibres and electrospun to produce nanofibres [27]. In comparison to conventional chemotherapeutic agents, nanoscale anticancer drug delivery agents proved the potential to control some of these side effects, such as toxicity in normal cells, thereby enhancing treatment efficiency through high selective accumulation in cancer cells for active cellular acceptance and better permeability and retention (EPR) effect [16, 52, 53]. Morie et al. and Rogalski et al. provided the reasons that their advantages of having reduced diameter, larger surface area to volume ratio, and tunable porosity make them electrospun nanofibres—superior to microfibrils [28, 62]. Various studies have been carried out to explore and increase solubility and delivery of anticancer drugs effectively [63]. Qualities of high functional characteristics possessed by nanofibres enable them to be applied as drug carriers, either as biodegradable or nonbiodegradable polymers in drug delivery systems [10, 28, 62]. The high porosities (holes) observed in images of nanofibres obtained from SEM are insertions for anticancer drugs in specific regions [35, 36, 62–66]. Porosity helps to deliver the drug by moving it from the membrane of the nanofibre to the blood of the subject's body [36, 63]. This will follow the implantation of the anticancer drug to the body [63]. In contemporary era, fibres infused with medication can be electrospun to give enhanced medicated nanofibres [64–66]. During drug delivery, these medicated nanofibres biodegrade, where the medication is uniformly released in the body [67–70]. In cancer research, two applications of electrospinning are as three-dimensional (3D) fibrous materials to produce *in vitro* pre-clinical cancer models and as blotches encapsulating anticancer agents for *in vivo* delivery [7].

7. Conclusion and Future Research

Basic principles of electrospinning as anticancer drug delivery system were reported to produce electrospun nanofibre. Anticancer drug infusion into nanofibres' pores will lead to transporting these drugs to the expected target for a successful delivery. Additionally, characterization techniques are used to assess their morphologies, sizes, specific surface area, porosimetry, contact angle measurement, thermal stabilities, structural changes, and chemical bonds to confirm successful fabrication of electrospun nanofibres. Future research will entail comparison of electrospinning and electrospun nanofibres as anticancer drug delivery systems.

Abbreviations

AFM:	Atomic Force Microscopy
BET:	Brunauer-Emmett-Teller
DNA:	Deoxyribonucleic acid
DSC:	Differential Scanning Calorimetry
EBSD:	Electron Back Scattered Diffraction
EDX:	Energy Dispersive X-ray Spectroscopy
FIB:	Focused Ion Beam
FTIR:	Fourier Transform Infrared Spectroscopy
PA6:	Polyamide 6
PAN:	Polyacrylonitrile
PVA:	Poly(vinyl alcohol)
SPM:	Scanning probe microscopy
SEM:	Scanning Electron Microscope
TG:	Thermal analysis
TEM:	Transmission Electron Microscope
TGA:	Thermal Gravimetric Analysis
WHO:	World Health Organization.

Data Availability

The data in the document and figures used to support the findings on this study are included within the research article.

Conflicts of Interest

Authors declare no conflict of interest.

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