Review Article

Nanofibers: An Auspicious Drug Delivery Conveyor

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ABSTRACT

Because of their unique physiochemical qualities and attributes, nanofibers have produced an interesting one-dimensional nanomaterial for research and biomedical applications. Electrospun nanofibers are being used including therapeutics varying from antibiotics and oncology medicines to proteins, DNA, RNA, cell lines, and other bioactive molecules. Nanofibers special properties, such as high loading performance, superior mechanical effectiveness (rigidity and tensile strength), controlled release rate of the drug, and high stability will aid in the future delivery of plasmid DNA, protein drugs, genetic materials, and autologous stem cells to the specified location. The specific surface area to volume ratio of nanofibers is extreme. There are only a few approaches for making nanofibers accessible right now: The Electrospinning techniques includes electrospinning, self-assembly, phase separation, template synthesis, drawing, fibers mesh technology, and fiber bonding technology. Among these, the electro-spinning is excellently used technique. Several medications with low solubility can be integrated into the fibers to improve the bioavailability of the drug and provide controlled release using this technology. The Methodologies used to fabricate Nanofibers and their high-tech applications in medication delivery, tissue engineering, and wound dressing are described in detail in this review. It also makes recommendations for the future inquiry and hurdles in the domain.

Keywords: Electrospinning, phase separation, Nanofibers, bioavailability, drug delivery, tissue engineering.

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INTRODUCTION

In past few years, the design and production of nanocarriers has fascinated considerable notice because of the inventive physical, chemical as well as biological attributes. From latest studies, it was accepted that nanocarrier materials are in form of nanoparticles, nanotubes, nanorods, nanodiscs and Nanowhiskers etc. Among the several nanomaterials, Nanofibers have mechanical attributes and fine pore. [1]

In the field of Medicine, nanofibers have different applications such as enzyme immobilization, tissue engineering, wound dressing, artificial organs, ophthalmology, and bone repair and drug delivery. [2]

Because of their unique structure, drug-loaded nanofibers have recently gained much attention as promising drug delivery applications. Many of the familiar drug delivery systems are administered by intestinal routes in the form of capsules, tablets, granules etc., where few are taken by routes other than enteric system such as intravenous, intramuscular, intra articular (or) subcutaneous. Such type of routes has some demerits like first pass metabolism, pain discomforts. These problems can be controlled by taking the active substances into nanofibers. [3, 4]

Nanofibers are fibers with a diameter of less than 50 nanometers and a length of less than 500 nanometers. Nanofibers are still being used in medical practices as a pharmaceutical delivery device for a range of disorders. They are mainly applied as drug carriers. Due to the small size, the nanofibers deliver the pharmaceutical agents (or) drug to the applicants in an acceptable manner. The intention of this drug carrier system is to provide a certain amount of medication in an efficacious, precise, and scheduled approach. [5, 6, 7] Polymer nanofibers are created using processes such as drawing, template synthesis, self-assembly, phase separation and electro spinning, fiber-mesh technology, and fiber-bonding methodology (Table 1).

Only discontinuous nanofibers are generated using the drawing procedure. The procedure of template synthesis is used to create fibers with specific diameters. Self-assembly method is used to produce fibers at very low speed and Phase separation is used only for some specific polymers, Although, Electro-spinning process provides the opportunity to synthesize nanofibers which are continuous and nanofibers with required varying dimensions. [8-10] (Figure 1)

Table 1: Different Techniques and their Advantages as well as Disadvantages of Nanofibers are Illustrated below

S.No	Techniques	Advantages	Disadvantages
1.	Electrospinning	Fibers with diameter varying from several nanometre range to some of those microns; low-cost approach; high surface to volume ratio; improved mechanical characteristics.	Huge-volume scaffolds are not easy to construct.
2.	Template synthesis	As a template, a nonporous membrane has been used.	It's impossible to make nanofibers that are long and continuous.
3.	Phase separation	Pore size and morphology are managed, and a variety of shapes and sizes are available.	Long continuous fibers are impossible to make; just a few polymers are available.
4.	Self-assembly	Nanofibers with uniform shape can be obtained.	Long continuous nanofibers are impossible to make; just a few polymers are available. Biomaterial's uses are restricted by their high cost of manufacture; tailored peptide nanofibers can be broken and are sensitive to endocytosis.
5.	Drawing	Extremely long single nanofibers can be formed.	Limited to viscoelastic materials; reliant on extrusion mould orifice size; challenging to create fibers with diameters smaller than 100nm.
6.	Fiber mesh technique	Large surface area and fast diffusion of nutrients.	Loading efficiency is less
7.	Fiber bonding technique	Cost effectiveness; simple; controlled pore size.	Structural instability.

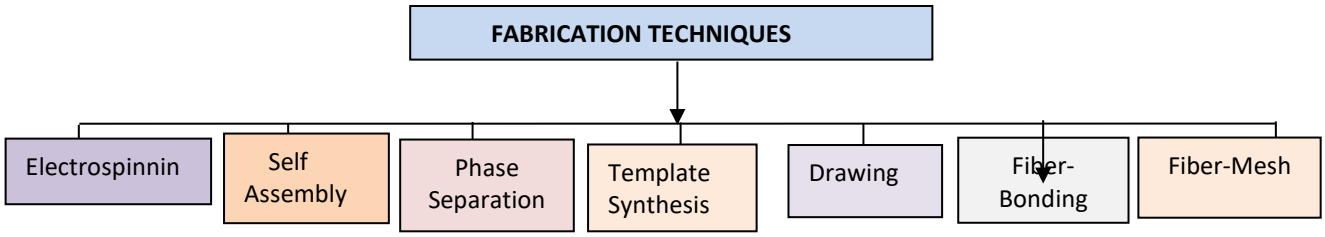

Figure 1: Illustrates the different fabrication approaches associated with Nanofibers.

Electro Spinning Technology

Electrospinning is a process for creating a tiny thread of polymer solution using electrostatic force. It is low priced method of nanofibers production by disclosing a polymer solution to electric field which is having high voltage. Fibers can be which are about 1000 times smaller in diameter when compared to hair of human beings (100 nm v, 100µm) whenever, when a very high voltage is given to the metal syringe needle, the solution generates an electric charge on its outside. The charge is impelled to an electrically grounded collector in our instance a piece of Aluminium foil as a charge jumps to the electric ground, a thin jet of polymeric solution is draw out from the needle. After the solution comes out of the syringe, the solvent in the solution evaporates and the very narrow stream of polymer is completing a circuit which begin with voltage energy source. Nanofibers are removed and imprinted on a grounded plate at the end of the process. (Figure 2)

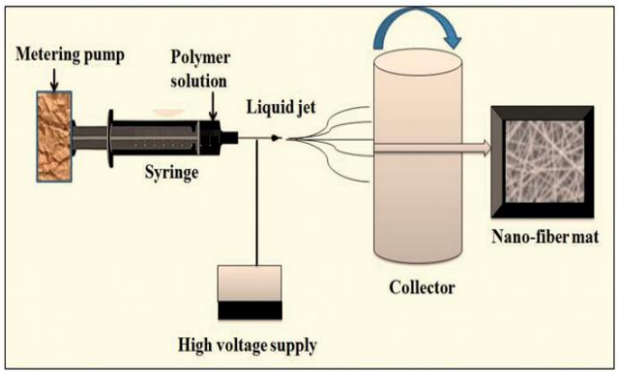

Figure 2: The manufacturing of nanofibers using the electrospinning technology is depicted in this illustration.

Electro-spinning technology has following interests:

1. The production of nanofibers are high.

2. Setup is simple, and cost of production is less.

3. One of the main quantities related with these techniques is diameter of fibers. If nanofibers are manufactured by evaporating or hardening polymer fluid jets, the diameter of the fiber will be determined primarily by the jet sizes as well as the polymer content. During the passage of solution, jet may or may not be divided into multiple jets, inferring in various fibers diameters. One of the most essential elements influencing the diameter of the fiber is large, as it does not divide. If a solid polymer is solubilized in a solvent with a faster speed of solution proportional to the polymer, the diameter of the resulting nanofibers would be bigger. The applied electric voltage is another aspect that has a massive effect on the diameter of the fibers. [11 12]

Fabrication of Nanofibers

A large variety of polymeric substances have been used as the delivery matrices, and selection of delivering polymeric vehicle is determined by the need of specific application. Polymeric nanofibers have modernly been explored for their capacity to bio-activate for the therapeutic applications.

Self-Assembly

Self-assembly consists of the voluntary organization of individual components and firm structure with preprogrammed noncovalent bonds. It is used in production of peptide nanofibers and peptide amphiphiles. Self-assembly is used for the synthesis of nanofibers which are very fine compared to nanofibers produced by electrospinning process, but the disadvantage is more tortuous methods and extremely detailed techniques is used for production. [13] (Figure 3)

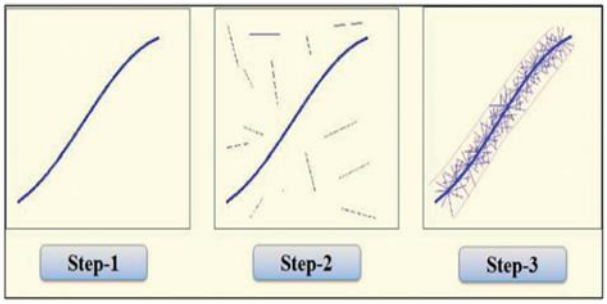

Figure 3: The manufacturing of nanofibers using the self-assembly approach is depicted in this diagram. [14]

Advantages:

1. It is simple technique
2. Easy process ability
3. They are produced in large amounts.
4. Nanofibers can be obtained with uniform shape.

Disadvantages:

1. It takes much time for production.
2. It is not used for laboratory purpose.
3. It isn't appropriate for all polymers.
4. Poor loading efficiency.
5. Porosity cannot be maintained for longer period.
6. The obtained nanofibers are highly water stable. [15]

Phase Separation Technique

In this process, different suitable solvents, dissolution, gelation, extraction is carried out and followed by freezing and drying condition which gives porous nanofibers. In this method, little quantity of homogenous polymeric solute is added to the suitable Teflon containers. The temperature of obtained gelation that depends on the concentration of polymeric solution, finally removes the gel from the container and freeze-drying process is used for keeping it dry. Concentration of polymer and temperature of gelation period. (Figure 4)

Nanofiber networks and platelet like structure are formed due to high (or) low gelation temperature. The nanofibers formed are porous structures with network of endless filaments. The morphology of nanofibers is further influenced by the type of polymer, solvents used, gelation temperature, gelation time and thermal treatment.

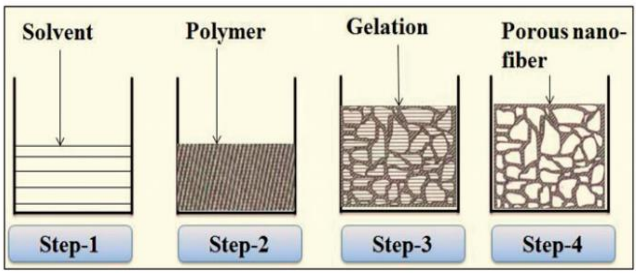

Figure 4: Illustration of fabrication of nanofibers by using Phase Separation method.

Advantages:

1. This method is simple.
2. Cost effective.
3. Mostly used for production of nanofibers.
4. Formation of continuous nanofibers and large production of nanofibers are possible.

Disadvantages:

1. Applicable only for laboratory scale production.
2. It takes more time for production.
3. Structural instability
4. Porosity maintenance is difficult.
5. Not used for all types of polymers. [16]

Template Synthesis

In this technique, a template is used to form a nanofiber of required structure. In general, the template refers to a membrane of metal oxide, the thickness through which the pores diameter is acquired. In this method water pressure is applied on one of the side and restraint from the porous

membrane, which squeezes out the polymeric solution. The solution becomes hard and turns into nanofibers. The pores determine the diameter of obtained nanofibers. By using various types of templates, fibers of various diameters can be obtained. However, it is complicated process for nanofibers production. [17] (Figure 5)

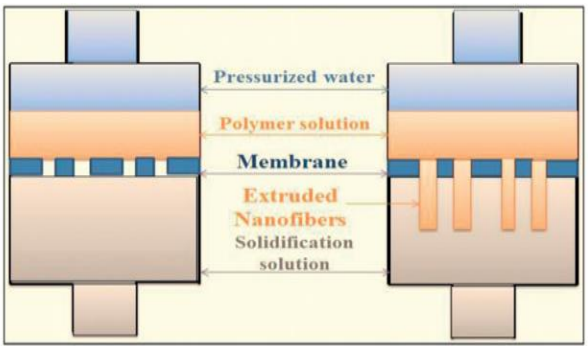

Figure 5: Template synthesis is used to fabricate nanofibers in this illustration.

Advantages:

The dimensions of the fibers are controlled by uniform pores which helps in production of nanofibers with very small diameters.

Disadvantages:

Continuous nanofibers cannot be obtained one at a time.

Drawing Technique

This is a technique which are used for synthesis of single strand of nanofibers one at a time. This technique is like dry spinning in fiber forming industry. This method mainly consists of three steps:

- Application of millimeter drop of polymer solution on the substrate material.
- Movement of micropipette towards the end of the drop and contact.
- Then the fibers are draw out of polymer droplet at a specific rate by back motion of micropipette and finally, liquid polymer is formed in nanofibers.

The composition of the material, velocity of drawing solvent evaporation speed is responsible for the quality of nanofibers. Different polymers such as PVS, PCL, blend of hyaluronic acid, polyvinyl butyral, Fish gelatin, PEO are well used for synthesis of nanofibers by this method. (Figure 6)

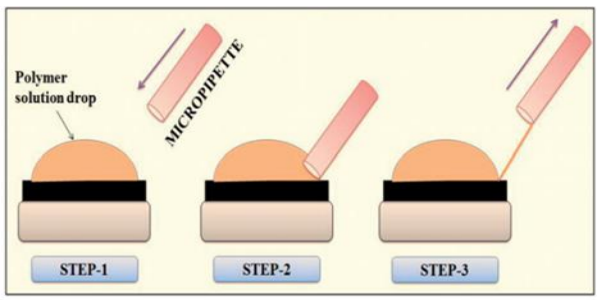

Figure 6: Illustration of fabrication of nanofibers by using Drawing technique.

Advantages:

1. This is an easy process.
2. It is easy to handle and cost effective.

Disadvantages:

1. It takes more time for production.
2. Not used for all type of polymers.
3. Very long single fiber is formed which is having poor shape.

Fiber Mesh Technique

In this method, non-woven mesh is obtained by deposition of polymer solution over another polymer and evaporated to form a nanofiber mesh.

Advantages:

1. Fast diffusion of nutrients.
2. Cell attachment is more.
3. Surface area is large.
4. Availability of favorable conditions survival and growth of the cell.

Disadvantages:

1. Structural instability.
2. Porosity maintenance is difficult.
3. Not used for all type of polymers.
4. Loading efficiency is less.

Fiber Bonding Technique

Several types of polymeric nanofibers brought together above the melting point temperature at their cross linked points, which lead to the production of nanofiber mesh.

Advantages:

1. Surface area is large.
2. Easy production.
3. Cost effectiveness.
4. Pore size can be controlled.

Disadvantages:

1. Mechanical integrity is poor.
2. Structural instability.
3. Residual organic solvents.
4. Porosity maintenance is not so easy. [18 19]

Polymer-Solvents Used in Electrospinning

Suitable solvents are used for the specific polymers. Then the polymer is solubilized in the solvent taken and solution was spun to form nanofibers of range 10-200nm diameter. Table 2 illustrates the list of few of the polymer solvent systems used in Electrospinning process.

Table 2: Polymers-Solvents Used for Electro-Spinning

Polymer	Solvent
PET	Dimethyl chloride/ trifluoroacetic acid
Nylon 6 and Nylon 66	Formic acid
Polybenzimidazole	Dimethyl acetamide
Polyimides	Phenol
P0lyamide	Sulfuric acid
Polyesters	DMF\Toluene
PVA	Water
Nylon 6-co-polymeride	Formic acid

Attributes of Nanofibers

1. Nanofibers are indeed a great replacement for drug and cell transportation owing to excellent biodegradability, biocompatibility, sterility, great mechanical characteristics, and controlled release mechanism.
2. They have such a remarkable potential to execute their encapsulated ingredients to the region of interest without causing any detrimental consequences.
3. Scaffold formulations of nanofibers shows very good biocompatibility with body tissues and incorporated substances.
4. Nanofibers have a significant biodegradable characteristics, and the breakdown products that have been easily removed from the placement site in the body are acceptable.
5. Nanofibers have a high trapping and drug loading capacity. As a result, it has an extra duration of continuous drug release after entry into the body.
6. Nanofibers' integrated pore structure enables for the best possible interaction with bioactive chemicals. [20 21]

Drug Loading

Drug loading of nanofibers can be accomplished by dissolving the pharmaceutical drug in some kind of a polymer solution before spinning the nanoscale fibers. The significant porosity of nanofibers helps promote product deterioration rapidly. The burst release might also potentially indicate that the medication is being applied directly to the skin. Because carrier materials and pharmaceuticals can be blended to make nanofibers via electrospinning, the drug form in the nanofibers obtained is:

The pharmaceutical, in the form of nanofibers, bound to the carrier system's surface as fragments.

The drug and carrier are in nanofiber form .so, the end-product will be 2 types of nanofibers which are joined together and form into one kind composed of both compounds.

The drug particles are enclosed in a tubular carrier material that has already been electrospun. [22 23]

Applications of Electospun Nanofibers

Nanofibers' therapeutic applications include tissue engineering, scaffolds, wound healing, drug administration via affinity membranes, health-care filtration, as well as enzyme immobilization, to highlight a few. This is due to their outstanding characteristics such as high porosity, high surface area to volume ratio and enhanced physiochemical properties.

Wound Healing:

The dressing protects the lesion by absorbing additional body exudates as well as aids in the wound healing process. The wound dressing material has a property which permeates the oxygen and moisture. It also provides physical barrier to wound. The wound dressing material should possess following attributes:

- The ability to absorb the excess excudates.
- The ability to exchange gases adequately.
- Bacterial barrier efficiency.
- Inexpensiveness.
- No pain and easy to remove.
- Electrospun nanofibers matrix is the optimal wound treatment medium due to its superior qualities; holes are tiny and surface area is extremely specialized. [24]

Drug Delivery Applications:

Nanofibers are applied for controlling delivery of drugs from hydrophilic and biodegradable polymers in medical therapy because of its ideal properties water soluble, poorly water soluble, water insoluble drugs and macromolecules such as bioactive proteins and DNA can be delivered in wide range by using nanofibers. [25] It protects drug from systemic decomposition. They have good permeability across BBB. They aid with the delivery of a medicine to a specific location. For example, carbon nanofibers carry drug into the blood cells because of its smaller size. Nanofibers are also used for preparation of different types of medical devices like sutures or bandages, which finally dissolves in body. Several therapeutic molecules, comprising antibiotics, anticancer medicines, proteins, polysaccharides, as well as growth regulators, have been synthesized into nanofibers for regulated topical drug administration over time. Electrospun nanofibers have several uses such as, drug delivery, topical drug delivery, tissue engineering, gene delivery& biomedical applications to enhance therapeutic efficiency. Also used as a vitamin carrier to skin.

Tissue engineering:

In tissue engineering, nanofibers are required to separate, supplement, store, or improve the performance of a certain tissue or organ. Electrospun nanofibers consistently

performed well even in terms of cell adhesion, proliferating, and penetration. [26 27]

Filtration:

In the domain of filter media, polymeric nanofibers are significant. To entrap the particles, the filtration needs have certain features. Polymeric nanofibers exhibit remarkable filtration capacities due to its elevated specific surface - to - volume ratio; Particles less than 0.5 nm can be easily trapped. Nanofibers are used in the Ultra-filtration as supportive scaffolds for separation of oil/water emulsions. The Ultra filtration filter has good organic capacity to reject the organic solvents. They are also employed to disinfect aerosol debris, pathogens and microorganisms in uniform clothing and isolated bags. By uniting the spinning and discharging of polymers into nanofibers throughout one step, the filtration effectiveness of nanofiber membranes could have been increased without raising pressure drop. [28]

Enzyme immobilization:

Electrospun nanofibers have been found to be excellent supports for inactivating enzymes due to their large surface area to volume ratio, pore diameter, diverse locations for interactions (or) attachment, and low transfer constraints. Some of the strategies for paralyzing enzymes on electrospun nanofibers comprise physical adsorption, implanting enzyme on fiber surface, and loading enzyme into nanofibers proceeded by a cross-linking step. Numerous researchers have worked on enzyme immobilization into nanofibers with high enzyme loading capacity using the co-electrospinning approach. Jia et al. used an electro-spinning approach to immobilize α-chymotrypsin and found that the immobilized enzymes had roughly 65 percent of the hydrolytic activity of free enzymes. [29]

Cosmetics:

Electrospun nanofiber membranes have been used in facial masks, perfumes, deodorants, as well as antiperspirants, to mention a few therapeutic applications. They've been employed as cosmetic skin care sheets with or without good ingredients for skin restoration, skin cleansing (or) other therapeutic or pharmaceutical functions. These skin masks have a large surface area allowing for a quick transfer of ingredients to the skin. Electrospun cosmetic skin masks can also be gently as well as conveniently placed on the three-dimensional structure of the skin for recovery or healthcare therapy. The new face mask increased product stability while also allowing for better skin penetration. The nanofibers mask will provide maximal contact with the topmost layer of skin and will aid in improving permeability of the cell membrane to restore its youthful skin. [30 31]

Factors influencing physiochemical properties of Nanofibers

Solution Concentration: The viscosity increases as the polymer concentration rises. The interfacial tension can sometimes be overcome by high viscosity, resulting in a stable Taylor cone. [32]

Applied Voltage: Change in the applied voltage have two vital effects on diameter of fibers. The electric field increases with the increase in voltage, increasing the jet acceleration and consequently its stretching, resulting fine fibers. Elevating the applied voltage, in any case, means that the mass of polymer extracted each second will grow.[33, 34]

Conductivity: An electric charge is passed from the electrode to the spinning droplet at the tip using only a limited amount of electric conductivity in solution. The solution's conductivity is a critical aspect in producing fibers that are uniform and devoid of beads. The concentration of polymer influences the solution conductivity. The electrical conductivity falls as when the polymer concentration is higher. Higher charge carrying ability and greater tensile strength fibers are obtained by highly conductive solutions. Zero conductive solutions cannot be electrospun.

Solvent Volatility: Solvent volatility has a consequence on fiber porosity. To acquire sufficient solvent evaporation, a volatile solvent should be used. Prior to the deposition of solid fibers onto the collection plate, phase separation occurs. The volatility of the solvent has a substantial impact on the phase separation process.

Tip to Collector distance: The consequence of spinning distance is having two aspects. Changing the spinneret to collector distance influences the time-of-flight of jet and electric field. Large quantity of fibers can be dawn out by expanding the distance and improves solvent evaporation, resulting fine fibers. Increasing the distance, however, lessens the electric field, causing the jet to accelerate to a lower magnitude, reducing stretching and widening fiber diameter. Hence, system dependence, enlarging the spinning distance can either expand or reduce the fiber diameter.

Surface tension: The impact of surface tension on the morphology is trivial and is not appropriately assessed. The surface tension of polymer solution could be controlled by carefully selecting the solvent. In general, the surface tension of polymer solution will be declined by the elevating the concentration of polymer. As with electric conductivity, the surface tension of polymer solution in existence of minimum concentrations of additives is modified.

Molecular weight: The molecular weight of the polymer solution to be electrospun must be sufficient. Even so if enough intermolecular interactions can be contributed via chain entanglements, electrospinning can take place in distinctive cases, viz. oligomer sized phospholipids non-woven from lecithin solution. The molecular weight influences other variables such as surface tension, viscosity, surface charge density, and electrical characteristics. If the solution concentration remains constant during electrospinning, reducing the molecular weight of the polymer will result in the development of more beads, and increasing the molecular weight will result in the development and manufacturing of smooth fibers, and

further continuing to increase it will result in the manufacture of nanoscale ribbon.

Flow rate: The diameter, geometry, and porosity of the electrospun nanofibers are all hindered by the flow rate of the solution. In ways to construct beadles' symmetrical fibers, the polymer solution must be given enough time to polarize. The researchers recommend a minimum flow rate, although for electro-spinning, a modest flow rate is required. The increase in flow rate is proportional to the increase in diameter and pore size. Yet, an excessively high flow rate supports the creation of beaded fibers.

Effect of Temperature: Elevated ambient temperature will result the declined solvent evaporation rate. Therefore, more time is taken by charged jet to undergo solidification. Additionally, there is reduction in viscosity of polymer solution and due to lesser viscosity, there are more stretching of fibers resulting fine fibers. [35]

Effect of Humidity: Change in Humidity during Electrospinning has greater impact on the morphology of electrospun nanofibers. Table 3 Illustrates the impact of various factors on the morphology of nanofibers.

Table 3: Effect of Various Factors on Morphology of Nanofibers

Polymer solution Concentration	Low Value ➡ Fiber Break Greater Value ➡ No Fiber formation
Temperature	High temperature ➡ Low Viscosity of Polymer ➡ High porosity
Volatility of solvent	Less volatile ➡ Less porosity More Volatile ➡ More Porosity
Applied Voltage	Sub optimal Volt ➡ beads irregular ➡ Drug release
Flow speed	Low Flow Rate ➡ Increased Fiber Diameter and beads ➡ Loading Problem
Tip to Collector Distance	Sub Optimal TCD ➡ Flattened Fibres ➡ Unpredictable Drug Release Pattern
Conductivity of Solution	Lower value ➡ Low fiber strength ➡ low physical strength.

Evaluation of Electrospun Nanofibers

Morphology analysis:

Scanning electron microscopy has been used to evaluate the shape and diameter of electrospun nanofibers. The diameter of the electrospun nanofibers has been assessed in at least ten separate areas on the fiber mat. On the SEM sample holder, a tiny portion of fiber mat has been sputter-coated using platinum. The SEM pictures were taken with a 15Kv accelerating voltage. The size distribution of the fibers was measured by employing SEM images.

Studies on drug polymer compatibility:

The drug polymer interaction within drug loaded nanofibers has also been studied using an infrared spectrometer. To generate sample pellets, electrospun nanofibers have been cut into small particles and pulverized with KBR. With a precision of $2cm^{-1}$, measurements were recorded around 4000 and 800 cm^{-1}. [36]

Drug loaded Nanofibers using Differential Scanning calorimetry:

Differential scanning calorimetry has been used for evaluating the melting point of drug as well as polymer in drug- loaded nanofibers. The samples were measured in a crucible before being covered and compressed with a press. Then the crucible was therefore positioned inside of the equipment there at sampling site. Using software acquired system, the suitable gas was delivered, and the samples were examined. In a nitrogen atmosphere, DSC was used to evaluate the samples weighing 2-5 mg at a scanning speed of 10 C/min and temperatures ranging from 0 to 250 C.

Swelling and weight loss:

The degree of swelling and weight loss can be obtained by using the following equation. Phosphate buffer saline (PBS) solution at room temperature for 24 hours has been used for both the samples for testing.

Degree of swelling = $(M_1\text{-}M_2)/M \times 100$

Weight loss = $(M\text{-}M_2)/M \times 100$

M = Initial mass of overnight dried electrospun nanofibers.

M_1 = Swollen nanofibers mass obtained after elimination of moisture on the surface by using the filter paper.

M_2 = Mass of leftover nanofibers upon vaccum drying M_1 at room temperature since a fixed mass is achieved. [37]

Drug entrapment efficiency:

Nanofibers loaded with drug are first dried at 40℃ to measure the entrapment efficiency of nanofibers and known portion of nanofibers mat is solubilized in suitable solvent. UV spectrophotometer has been used to analyze the amount of drug in the appropriate solutions. The below equation has been used for determining the efficiency of entrapment.

Entrapment efficiency is defined as the ratio of the actual amount of drug to the therapeutic amount of drug divided by 100.

Tensile strength of Nanofibers:

The Brookfield texture analyzer has been used to assess the tensile strength of nanofibers. With using clamps, nanofibers approximately 6 cm in breadth were oriented vertically along the analyzer's axis. After then, the instrument was permitted to operate with a sensitivity force of 3 gm.\cm^2.The force needed to break the mat into two sections was then evaluated.

Future Prospective and Challenges

Tissue engineering, wound dressing, pharmacological and therapeutic agent administration are just a few of the uses for nanofibers in healthcare and biomedical engineering. Due to their unique structural and physiochemical properties, high surface area and porosity of network, Nanofibers are more attractive for immobilizing various active species and biomolecules. Therefore, their high molecular loading efficiency provides them advantageous for drug delivery and biological sensing applications. However, even with these encouraging characteristics, there are still some confronts facing the practical applications of nanofibers in biomedical and health applications, for example, for further improvement of applicability of nanofibers, for biomedical applications, several physical attributes of nanofibers and their network structure like size arrangement, porosity, orientation, need to be controlled and optimized carefully.

Nasal muco-adhesive nanofibers electro-spun nanofibers could be applicable for delivering proteins, peptides, and DNA, RNA therapies. It is also having great application in the vaginal mucosa. Regardless of the fact that electro-spinning is the most widely used process for making nanofibers, it comes with several drawbacks, particularly for producing electrospun nanofibers-based controlled drug delivery.

The construction of nanofibers is much more expensive than manufacturing nanofibers with regular fibres that's because the methodology seems to have a high cost and low annual production. The major challenges connected with its fabrication is good control over the physiological properties of nanofibers.

CONCLUSION

Nanofibers have become increasingly popular in recent years, particularly in controlled drug delivery systems, due to several advantages such as high porosity and a high surface area to volume ratio. The most prominent way to design nanofibers is electrospinning. A few issues, such as active agent instability, initial burst effect, and integrated use of biocompatible polymers, should be considered for future use. By improving huge manufacturing procedures, high-quality nanofibers can be obtained. According to upcoming developments and new discoveries, nanofibers will be supported in the future, and clinical investigations will be undertaken soon. Because of the structural characteristics of nanofibers, the drug delivery system using electrospun nanofibers has been enlarged with synergistic benefits.

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