WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Review on Electrospun Fibers and their Biomedical Applications

Junghare Shekhar *, Shewale Suraj, Bhosale Vasundhara, Kank Snehal, Salunkhe Kiran, ShaikhApsana

Department of pharmaceutics, Shree Santkrupa College of Pharmacy,Ghogaon, Maharashtra.
shekharjunghare9@gmail.com

ABSTRACT

Nanotechnology is favoured for a variety of biomedical applications. Using electrostatic repulsive forces, the electrospinning process generates ultrafine fibres. The method has gotten a lot of interest because of its potential applications in biomedicine and medication delivery. Although electrospinning was found many years before, it was thanks to the efforts of Formhals in 1934. However, as a simple and flexible technological instrument for the creation of nanofibers, it has sparked a lot of attention. Electrospun fibres have a nano to micro size range, a porous structure, and a high surface area to volume ratio. Electrospinning allows for greater flexibility and diversity in nanofiber production by optimising process parameters. Nanofibers have a variety of uses in medication and gene delivery, wound treatment, and tissue engineering. Implants, transdermal systems, wound dressings, and devices to help prevent postsurgical abdominal adhesions and infection all employ drug-loaded electrospun nanofibers. The study highlights the uses of electrospun fibres in biomedical domains such as drug administration, wound dressing, enzyme immobilisation, and tissue engineering, which encompasses vascular, nerve, bone, and tendon/ligament tissue engineering. Other uses include adsorption, sensor technology, cosmetics, and electrical and optical applications.

INTRODUCTION

Electrospinning is a polymer fibre development process that uses electrostatic forces to produce very thin polymer fibres with diameters ranging from submicron to manometer. The method may be used to make fibres out of natural, biodegradable, nondegradable, or mixed polymers. 1 Phase separation, self-assembly, template synthesis, and mechanical drawing are three traditional methods for producing polymeric fibre. Electrospinning is chosen because it is simple to use, cost-effective, and can be used to produce ultrafine fibres with simple step-up production that is difficult to do with other traditional fiber-forming processes. [2]

A high voltage electric field is supplied to the polymer liquid solution or melt during electrospinning. The surface tension of the liquid holds the polymer droplet at the capillary tip in the absence of an electric field. The droplet elongates and develops into a "Taylor Cone" when an electric field is introduced and the liquid surface tension is balanced by the applied electrostatic forces. A fine fibre jet is expelled from the tip of the Taylor Cone when the electrical field is strong enough to overcome the liquid's surface tension. The solvent evaporates as the fibre jet passes through the atmosphere, and solid polymer fibres are deposited as a mesh or scaffold on a grounded collector. [3]

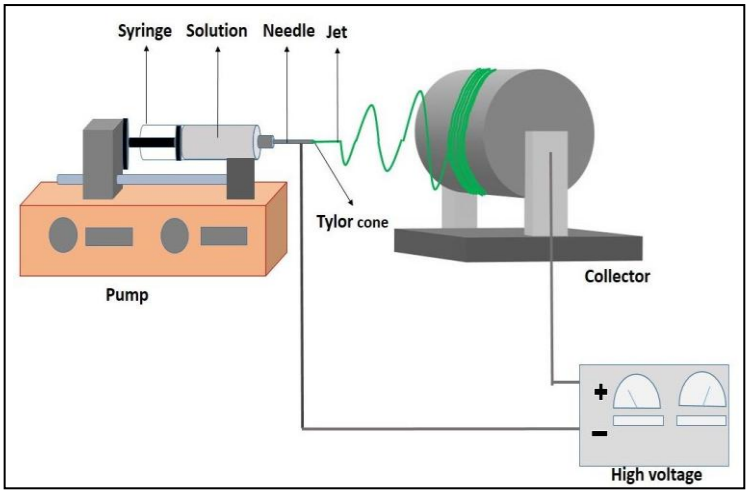

Fig. 1: Electrospinning setup

Electrospinning's surface characteristics and diversity lead to applications in a variety of sectors. Drug administration, gene delivery, postoperative adhesion avoidance, wound dressings, and tissue engineering are all applications for electrospun nanofibers. Artificial vascular graft constructions, as well as neural tissue, tendon and ligament tissue, and bone tissue, are among the tissue engineering uses of electrospun nanofibers. Sensors for the detection of gases, chemical compounds such as urea, and medicines such as anticancer medications are made with electrospun nanofibrous membranes (e.g., daunorubicin). Electrospun nonwoven mats are utilised for air filtration and have been successfully manufactured as high performance air filters like HEPA filters and filters with a high filtration

Wound dressing

Wound dressing creates the ideal environment for wound healing. Dressings are an appealing wound-healing alternative. Fluid absorption, thermal isolation, and medication administration are all provided while the surrounding skin at the wound site is protected. Microbial development and bacterial multiplication are inhibited by the antimicrobial action of the dressing. A superior wound dressing has a low water contact angle and absorbs exudate from an open wound quickly. 4 Wound dressings are classified into three categories, according to Zahedi et al. The first is passive wound dressing, which consists of gauze that just covers the wound, and the second is interactive material dressing, which provides gas permeability while inhibiting bacterial movement. Dressing with bioactive materials is the third option. 5

Wound dressings provide protection, eliminate exudates, and prevent the entry of foreign microorganisms. If the blister is not burst, it will heal faster, and a blocked wound dressing will heal the wound properly. The wet, warm, and nutrient-rich environment of wound beds promotes microbial development. Provision for a moist atmosphere should be included in the ideal dressing. 6

Polymeric nanofibers are utilised in the treatment of human skin lesions and burns. Electrospun fibres create a gas permeability biomimetic environment for skin cell production during wound healing. Because of their narrow pore size distribution, fibres prevent bacterial infiltration at the wound. 7 Electrospun fibre films feature holes ranging in size from 500 nanometers to 1 micrometres, which are tiny enough to prevent bacterial penetration. 8 When electrospun fibres are loaded with drugs, they have a wide surface area, which improves wound healing. 7 Fibers film has a surface area of 5-100 m2/g and is effective for fluid absorption and cutaneous administration. 8

Wound healing using nanofibrous mats is far superior to the traditional wound dressing procedure. Fibers' large surface area and microporous nature aid wound healing by recruiting fibroblasts to the skin's derma layer. Collagen and numerous cytokines, such as growth factors and angiogenic factors, are excreted by fibroblasts and are crucial in the healing of injured tissue. 6

Tissue engineering

Tissue engineering was defined by Langer and Vacanti in 1993 as "an interdisciplinary discipline that uses engineering and life sciences concepts toward the creation of biological replacements that restore, maintain, or improve tissue function." 9 Tissue engineering's main objective is to heal or regenerate damaged tissue using a variety of biomaterials, cells, and bioactive agents. Ex vivo technique includes isolating cells from the patient and growing them on the scaffold. After that, the patient's damaged location is implanted. Following in situ tissue development, a scaffold is delivered directly to the damaged location. Scaffolds are first employed as a temporary and artificial extracellular matrix (ECM) for growing cells, but they are also utilised as a reservoir to transport bioactive chemicals to damaged tissues. 10

For tissue scaffold preparation, electrospinning is a highly useful technique. Micron to submicron nonwoven mesh is created in this technique. Different types of scaffolds, including bone, dentin, collagen, liver, cartilage, and skin, have been developed for human tissue research. The scaffolds may be produced using both natural and synthetic polymers. Electrospun fibres can be used to repair, replace, and improve tissue characteristics. Electrospun fibres require dimension consistency to create the scaffold. Other criteria in tissue engineering employing electrospinning include excellent pore size distribution, high surface area, biodegradability, the ability to preserve structural integrity with tissue, strong mechanical characteristics, nontoxicity to cells, and biocompatibility.[11]

Working on the ECM has a positive effect on the human body's reaction to cell healing (extracellular matrix). It is made up of carbohydrate polymers and fibrous protein polymers like as collagen and glycosaminoglycans (proteoglycans). Electrospun fibrous mats have a porous characteristic comparable to the extracellular matrix in the body. When scaffolds made of polymers that attract and mix with cellular attachment seen in the natural ECM, nanofiber efficiency improves (e.g., collagen). Collagen provides the single fibre with the requisite tensile mechanical characteristics, however it has limited potential to be employed as the only material in scaffolding in biomedical applications. because of low bulk properties. Collagen fibres have been produced with different biodegradable polymers by a number of studies since electrospinning collagen fibres is not cost effective. These composite materials improve collagen's interaction with cells while also providing strong mechanical characteristics. Many electrospun polymer fibres are used successfully in tissue engineering. 12

Core/shell nanofibers are also used in tissue engineering applications. The nature of fibres allows for the encapsulation of physiologically important chemicals and nano composites, as well as the modification of electrospun fibre surfaces. The electrical and mechanical characteristics of nanofibers are critical in tissue engineering applications. Single wall carbon nanotubes (SWNT) were combined with biodegradable poly (lactic acid) to create conductive electrospun nanofiberous scaffolds. The nanofiber scaffolds included into SWNT allow cells to develop without being harmed in any way. 13 Zhang and his colleagues synthesised collagen surface coated poly (-caprolactone) (PCL) nanofibers by coaxial electrospinning, and they investigated PCL cell-scaffold interaction on human dermal fibroblasts as a model for skin tissue engineering. 14

The electrospinning is used in the engineering of various tissues, for example, vasculature, nerve, bone, and tendon.

A. Vascular tissue engineering

Only clinically authorised synthetic replacement materials for coronary arteries in cardiovascular disease are used in vascular tissue engineering. For large diameter vascular grafts, polytetrafluoroethylene (ePTFE) and Dacron are utilised. For researchers, thrombus development, occlusion, and intimal hyperplasia, as well as the manufacturing of tiny diameter vascular grafts, is a difficult task. For this type of job and difficulty, surface alteration is beneficial. 15 Endothelial cells (EC) have antithrombotic characteristics, therefore researchers modified the surface of electrospun nanofibers to improve the endothelialisation process. To accomplish fast endothelialisation, EC trapping ligands were employed. Coting of an arginine- glycine-aspartic acid (RGD)-containing compound Nap-FFGRGD with a small-diameter nanofibrous vascular graft composed of poly(e-caprolactone) PCL. To produce an RGD- containing layer, this molecule of RGD and hydrophobic naphthalene groups self-assembles on the hydrophobic surfacePCL grafts and RGD–PCL grafts after 2 and 4 weeks after implantation in rabbit carotid arteries. The EC on the RGD–PCL was attached, as evidenced by this. Randomly aligned EC was discovered on the PCL graft. The endothelialisation rates of RGD–PCL grafts are considerably quicker than those of PCL grafts, according to the findings. 16

B. Nerve tissue engineering

The use of electrospinning in nerve tissue engineering has shown that stem cells can be differentiated into a variety of particular cells. In vitro studies of scaffold in nerve tissue engineering are conducted using stem cells. They offer neuronal differentiation, neurite outgrowth, and connection to neighbouring cells after planting and cultivating undifferentiated human embryonic stem cells on electrospun polyurethane nanofibrous scaffolds. 17 Highly aligned fibres are essential to prevent axonal outgrowth deviation on fibres and delayed axonal extension from one end to the other in a scaffold. Crossing fibre has a negative impact on directed axonal outgrowth. The topography of the substrate influences the shape of the stem cell, as well as its growth, survival, and gene expression differentiation. When compared to random PCL fibres, aligned PCL fibres offer superior neuronal development of adult neural stem cells. 18

C. Bone tissue engineering

Collagen (an organic component) is a component of bone's extracellular matrix (ECM). It is mostly composed of and HAp (inorganic component). HAp/PLLA, beta-tricalcium phosphate (b-TCP)/poly(e-caprolactone) (PCL), HAp/PLLA/collagen, HAp/PLLA/poly-benzyl-L- glutamate (PLBG)/collagen, and b-TCP/PCL/collagen are some examples of scaffolds. 19 In the cell proliferation and differentiation process, rat osteosarcoma cells on scaffold micro-sized HAp particles outperform nano-sized HAp particles. Mechanical strength of b-TCP/PCL fibres is affected by the relative quantity of b-TCP. The polypeptide poly-benzyl-L-glutamate (PLBG) improves cell adhesion and differentiation. The osteoconductive characteristics of HAp and the calcium binding capacity of PLBG are responsible for this rise. The inclusion of collagen improves the water absorption of the composite fibres, preventing the loss of bodily fluid and nutrients. 20

D. Tendon/ligament tissue engineering

The electrospinning method is also used in tendon/ligament tissue engineering. Tendons and ligaments connect muscles to bones. Tendons are connective tissues that are fibrous in nature. Bones are joined together by ligaments. Collagen type I makes up the majority of tissue ECMs. Others are used in scaffolding as well. Tendon scaffold and Antheraea pernyi silk fibroin are utilised as raw materials in the electrospinning process. The scaffold was tested in vitro and in vivo in New Zealand white rabbits with a gap defect in their Achilles tendon, with the development of tenocytes on scaffolds and the regeneration of tendon tissue. Tenocytes developed and multiplied on the scaffold in vitro, and after 16 weeks of in vivo implantation,homogeneous, well-oriented bundles of collagen fibres were produced in the neo-tendon tissue. 21

Tissue engineering facilitates cell adhesion and proliferation by growing cells in situ on a scaffold that mimics an extracellular matrix. The primary issues that arise throughout the procedure are the body's rejection of implanted scaffolds and the production of excessive reactive oxygen species (ROS) that cause oxidative damage. In engineering, antioxidant activity reduces ROS to avoid or decrease oxidative damage. Because it stops cells from growing. The study looked at a number of bioactive compounds with antioxidant activity as well as anti-inflammatory and/or antibacterial characteristics, biodegradability, and biocompatibility. In Skeletal muscle tissue engineering (SMTE) and large-scale applications, the scaffold should be adjustable to various desired formats.[22]

Nanofibers with conducting characteristics, antioxidant activity, biodegradability, and biocompatibility were created by combining melanin (a natural polymeric pigment) with silk fibroin, according to Manchineella and Nune et al. They measured reactive oxygen species (ROS) in myoblasts grown on scaffolds and other antioxidant activities with a DPPH test for random and aligned fibres to assess oxidative stress management. In comparison to SF nanofibers, melanin decreased myoblasts' intracellular ROS levels and improved cell proliferation. In the case of randomly oriented fibres containing melanin, DPPH radical scavenging was above 40%. 23

Enzyme immobilization

The electrospun fibres' characteristics, such as high specific surface area and porosity, substantially reduced the matrix's diffusion resistance and enhanced the loaded enzyme's catalytic activity. Enzyme immobilisation is the surface loading technique for Electrospun fibres. Active functional group

loading, chemical crosslinking, and surface modification are all methods used. Basturk uses surface covalent bonding to electrospun polyvinyl alcohol/polyacrylic acid (PVA/PAA) nanofibers with diameters ranging from 100 to 150 nm to immobilise a-amylase. The temperature inactivation resistance of immobilised a-amylase was higher than that of free amylase. 24 By dissolving PVA electrospinning nanofibers in keratinolytic protease solution, keratinolytic protease immobilised PVA electrospinning nanofibers were created. In circumstances of greater temperature and a wider pH range, the keratinolytic protease immobilised on PVA nanofibers improved activity and stability. 25 By incubating the electrospinning fibre mat in protein solution, the amylase and protease were covalently bound onto electrospun poly(styrene-comaleic anhydride) nanofibers with partial retention of their enzymatic activity. It indicates that when amylase is co-immobilized with protease, it retains its catalytic activity. 26 Electrospinning was utilised to create PVA/Zn2+ polymer/ionic metal composite nanofibers that were used as carriers in lipase immobilisation. Because of the water solubility of PVA, the PVA/Zn2+ composite nanofiber needed to be cross-linked before lipase immobilisation. To make waterinsoluble nanofibers, the hydroxyl groups of PVA and the aldehyde groups of glutaraldehyde were crosslinked at room temperature for 24 hours. The lipase immobilised nanofibers were then submerged in a water- insoluble nanofiber solution. The lipase immobilised nanofiber's enzymatic stability was enhanced. After 40 minutes at 700°C, the lipase immobilised PVA/ Zn2+ nanofiber maintained 90% activity, but the free lipase lost all activity. 27 For phenol removal, horseradish peroxidase (HRP) immobilised magnetic Fe3O4/polyacrylonitrile (PAN) electrospinning nanofibers were produced. Because of the magnetic synergy of Fe3O4 nanoparticles, the HRP immobilised Fe3O4/PAN electrospinning nanofibers with 40% Fe3O4 nanoparticles loading exhibited the lowest HRP loading but the maximum activity. 28 Electrospun fibre offers greater benefits than alternative enzyme carriers. Electrospinning has been more popular in the field of enzyme immobilisation in recent years. Electrospinning was used to create fibres that immobilised b- D-galactosidase, xylanase, glucose oxidase, naringinase, and laccase. Currently, the surface loading technique is used to immobilise enzymes in electrospun fibres. Varied loading mechanisms result in different enzyme-fiber binding capabilities. The exploration of enzyme applications will be greatly aided by considering novel loading mechanisms. 29

Drug delivery

Medication delivery systems are created to allow for the controlled release of a drug over a set length of time. In the field of drug delivery systems, electrospinning is a useful technique. Its capacity to manufacture nanofibers, which are chosen as medication carriers. It is a superior choice in drug delivery due to functional features such as large surface area, which is linked with improved dissolving rate, ease of drug integration, and restricted time for drug recrystallization due to quicker solvent evaporation. 10 As a carrier for electrospinning, natural and synthetic, biodegradable and non-biodegradable polymers, as well as a mix of both materials, have been utilisedElectrospun fibres have been formulated with pharmaceutical medicines such as anticancer treatments and antibiotics, as well as protein, DNA, and RNA. Drug diffusion and breakdown of the carrier polymer affect the drug release behaviour. To regulate the drug's distribution state in the fibres and hence enhance drug release kinetics, several electrospinning methods are utilised. 30

The electrospinning processing setup includes two approaches: mix electrospinning and coaxial electrospinning. Blend electrospinning includes mixing the polymer and biomolecules before electrospinning, whereas coaxial electrospinning involves electrospinning both polymer and biomolecules at the same time to generate fibres with a core–shell structure. 10 In the administration of drugs or medicines to patients, a physiologically appropriate approach has long been considered. When a medication is adequately encapsulated in dose, it is absorbed by the human body. When a smaller dimensional medication and coating material are utilised to encapsulate the medicine, better absorption is attained. The rate of drug dissolution rises as the surface area of both the medication and the carrier employed in the formulation increases. The use of electrospun fibres aids in medication encapsulation. Electrospun fibres can offer continuous and pulsatile release, as well as fast, immediate, delayed, or modified dissolution. The fibres have various topologies when drug and carrier materials are combined together for nanofibers. When the carrier is formed into nanofibers, drug particles are attached to the surface of the carrier, according to one structure. Both the medication and the carrier are dispersed in the fibre length and diameter in another configuration. The structure resembles core-shell nanofibers when the carrier material is electrospun as an exterior covering and drug particles are enclosed in tubular shape. 8 Many restrictions exist in cancer treatment, including clinical toxicity in radiation, toxicity to healthy cells caused by medication overload in chemotherapy, and restricted drug dispersion in blood vessels. Nanofibers are being used in cancer therapy to deal with such situations. To provide a safe and effective cancer therapy, Zhou and colleagues used the co-axial E-spin method to create doxorubicin core-shell nanofibers as an implant material. They utilised folate-conjugated PEG/PCL copolymer layered micelles in their research. Electrospun core-shell fibres assist in overcoming constraints such as the drug's inability to traverse blood arteries, its restricted solubility, and its nonspecific absorption. 31 Electrospun caffolds have a high surface area–volume ratio, indicating efficient medication administration. Drugs have been effectively incorporated into nanofiber scaffolds in the past. Therapeutic medicines are integrated into nanofibers by dissolving them in the electrospun polymer solution. Burst release might potentially suggest that the medication is solely bonded to the nanofibers' surface. Fibers with a tubular structure that induce a bioactive chemical. Within the nanofibers, it creates a more effective platform for drug and gene delivery systems. By altering the solution components, DNA is encapsulated inside the fibres, resulting in delayed release kinetics. Different release rates may be achieved by simply changing the fibre diameter or loading dose. 9 Electrospun fibres can accomplish targeted applications like as oral drug administration, colontargeted drug delivery, fast-dissolving drug delivery, sequential chemotherapy, and even the prevention of HIV transmission by modifying material selection and processing parameters. When the tablet is topped with thinner sheets and a burst release occurs early on. The late-stage medication release was regulated using a tablet topped with thicker sheets. A linear medication release profile was predicted if two distinct tablets were combined correctly. 10 Drug loading restrictions are present in traditional drug delivery techniques; however, the large surface area of nanofibers bypasses this barrier. The surface area of nanofibers increases much more when the fibre has a porous structure than when the nanofibers have a smooth surface. It has been discovered that electrospinning parameterssuch as mesh size and fibre diameter may be optimised to regulate medication release. 13

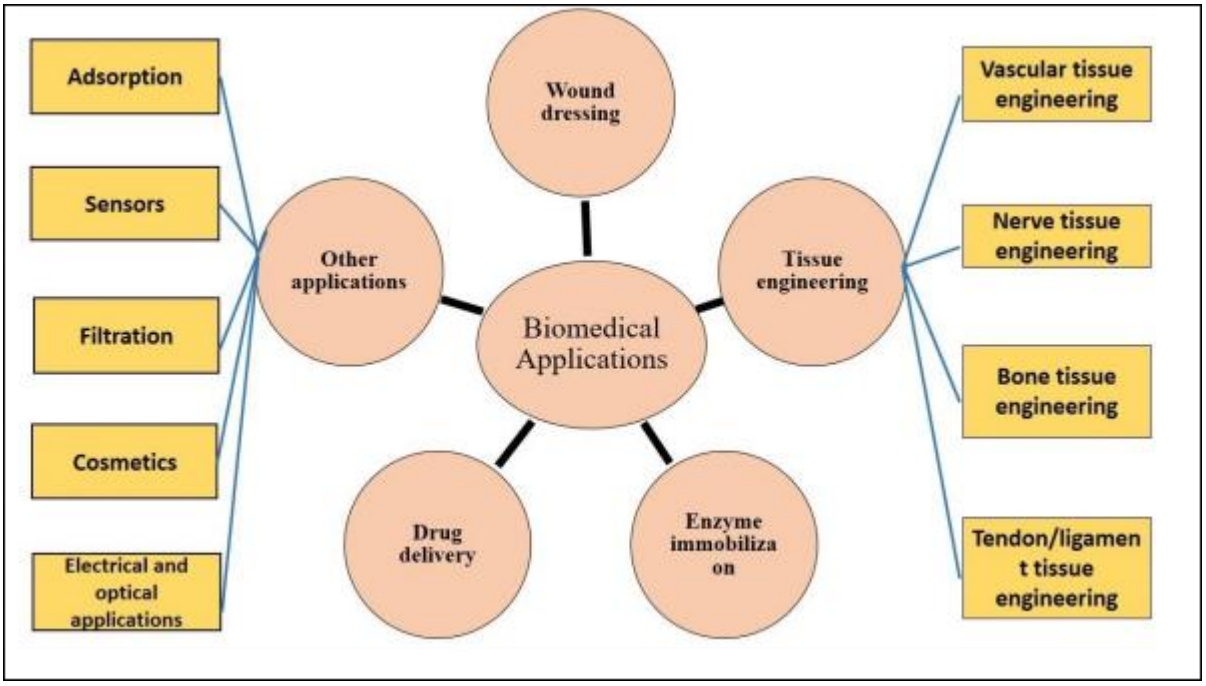

Fig. Biomedical application of electrospun fibers

Other applications

E. Adsorption

In the realm of adsorption and extraction, electrospun nanofiber mats are quite helpful. Oh, and coworkers make nanofibers to enhance the adsorption capacity of toluene. Toluene is a pollutant that is made up of a volatile organic molecule. Its level in the atmosphere must be kept under control. Carbon nanofibers were made using polyacrylonitrile nanofibers and then activated at 1000°C. The high surface area (1403m2/g), large micropore volume (0.505 cm3/g), and narrow average pore diameter (6.0A) of activated carbon nanofibers (ACNF) resulted in an excellent adsorption capacity of 65 g-toluene/100 g-ACNF, which they attributed to the ACNF's high surface area (1403m2/g), large micropore volume (0.505 cm3/g), and narrow average pore diameter (6.0A). 32 Kang and colleagues electrospun the nanofiber web and collected it on a copper grid using a polystyrene solution. They devised an electrospun nanofiber solid-phase extraction sorbent to extract trazodone from human plasma. Trazodone was isolated from samples that were pushed through this sorbent. After washing the sorbent with water, the analytes were eluted with methanol. High-performance liquid chromatography was utilised to examine the methanol used for elution (HPLC). The authors discovered that this approach of trazodone extraction and analysis was effective. 33

F. Sensors

Biosensors are required in the food, health-care, environmental sensing, and pharmaceutical industries. The electrospinning area is focused on the creation of small, portable sensors with high sensitivity. Electrospinning addresses these concerns by producing ultrafine nanofibers with high porosity in the submicron range. Electrospun nanofibers have a multiple-fold higher surface-to-volume ratio than any other system. Because increased surface area allows for enhanced absorption, such surfaces are effective in sensing minute amounts of analytes, such as gases, while being compact in size. Urea, glucose, cauliflower mosaic virus, DNA, cholesterol, hydrogen peroxides, catechol, amines, alcohols, nitrogen dioxide, and carbon monoxide have all been detected using electrospun membranes in biosensors. Polyaniline, polyamic acid, polypyrrole, nylon-6, PVA, and chitosan are some of the polymers that have proven effective in the fabrication of biosensing nanofiber mats. Researchers are now looking into the use of nanofiber mats in electrochemical and optical sensors. 34

G. Filtration.

Electrospinning creates ultrathin nanofibers, which can be used to improve air and liquid filtration membranes. The nonwoven electrospun mats are being utilised as high-performance air filters with great success. The high surface-to-volume ratio and cohesive characteristics of polymer nanofibers aid in the removal of airborne particles as tiny as 1–5 m. Charge was applied to the fibre surface in order to improve the filtering effectiveness of nanofiber mats without increasing the pressure drop. 34 Using an electrospinning method, Ahn and colleagues created Nylon 6 nanofilters. The authors compared the nanofiber filters' filtration performance and pressure drop to that of HEPA filters. The created nylon 6 nanofilters had a filtering effectiveness of 99.993 percent, according to the researchers. Antimicrobial filters have also been developed using electrospun matting. The usage of

electrospun cationomers with quaternary ammonium groups as nanofilters against harmful bacterial strains of Staphylococcus aureus and Escherichia coli has proven effective. 35

H. Cosmetics

Cosmetics that are administered as topical creams, lotions, or ointments may include dusts or liquid sprays that can migrate into sensitive body regions like the nose. With or without different additions, electrospun polymer nanofibers have been utilised as a cosmetic skin care mask for the treatment of skin healing, skin cleaning, or other therapeutical or medicinal characteristics. The nanofibrous skin mask's tiny interstices and large surface area allow for higher usage and a faster rate of additive transfer. The cosmetic skin mask made from electrospun nanofibers may be applied softly and painlessly on the three-dimensional topography of the skin to give healing or skin care therapy. 8

I. Electrical and optical applications

Conductive nanofibers are used to make Schottky junctions, sensors, and actuators, which are small electronic devices or machines. Because the rate of electrochemical reactions is related to the electrode's surface area, conductive nanofibrous membranes can be used as a porous electrode in the development of high-performance batteries. Electrostatic dissipation, corrosion prevention, electromagnetic interference shielding, photovoltaic device, and other applications can all benefit from conductive (electrical, ionic, and photoelectric) membranes. [8] Waters et al. employed electrospun nanofibers in the creation of an optical shutter liquid crystal device that can be switched by an electric field. Which is largely transparent to incoming light and which is significantly opaque to incident light. The primary component of this liquid crystal device was a layer of nanofibers saturated with liquid crystal material and measuring just a few ten microns in thickness. The layer was sandwiched in the middle of two electrodes. To alter the transmission of the liquid crystal/nanofiber combination, an electric field might be applied across the layer. 36 The sensitivity of the refractive index differences between the liquid crystal material and the fibres are determined by the fibre size, which affects the device's transmissivity. As a result, nanoscale polymer fibres are required in such devices.

Table no. 1: polymers and their applications

Sr. No.	Polymer used in electrospinning	Applications	Author	Reference
1	Poly (ε-caprolactone	Tissue engineering	Zhang et. al.	14
2	Melanin	Tissue engineering	Manchineella et. al.	23
3	Polyvinyl alvcohol and Polyacrylic acid	Enzyme immobilization	Basturk et. al.	24
4	PEG/PCL	Drug delivery	Zhouand et. al.	31
5	Polyacrylonitrile	Adsorption	Oh et. al.	32
6	Polystyrene	Adsorption	Kang et. al.	33
7	Nylon-6	Filtration	Ahn et. al.	35

Conclusion

In recent years, biomedical applications and other nano-techniques have given electrospinning a renewed emphasis. The process produces fibres with a high surface-to-volume ratio, is simple to operate, and is cost-effective. Because of these characteristics, the method is a better fit for biological applications. Co- and multi-nozzle electrospinning, as well as co-axial electrospinning, operate with a wide range of materials, including natural and manmade polymers, as well as their composites. These are electrospun into ultrathin fibres with morphologies and diameters that can be controlled. Their use in drug administration, wound dressing, enzyme immobilisation, and tissue engineering, which encompasses vascular tissue engineering, nerve tissue engineering, bone tissue engineering, and tendon/ligament tissue engineering, is discussed in this study. Other uses include adsorption, sensor technology, cosmetics, and electrical and optical applications. The morphological structure of fibres is used in all of these applications. Electrospinning technology may generate necessary kinds of fibres with correct material selection and parameter optimization.

REFERENCES

[1] Baumgarten P. Electrostatic spinning of acrylic microfibers. Journal of colloid and interface science. 1971; 36(1): 71–79.

[2] Doshi J., Reneker D., electrospinning process and applications of electrospun fibers. Journal of electrostatics. 1995; 35(2-3): 151–160.

[3] Liang D., Hsiao B., Chu B. Functional Electrospun nanofibrous scaffolds for biomedical applications. Advanced drug delivery reviews. 2007; 59(14):1392–1412.

[4] Vilchez A., Aevedo F., Cea M. Applications of electrospun nanofibers with antioxidant properties: a review. Nanomaterials. 2020; 10(175);1-28.

[5] Zahedi P., Rezaeian I., Ranaei-siadat o. A review on wound dressings with an emphasis on electrospun nanofibrous polymeric bandages. polym. Adv. technol. 2010; 21:77–95.

[6] Bahrami S., Kanani J., A review on electrospun nanofibers scaffold and biomedical applications. trends biomater. 2010; 24(2):93-115.

[7] Zhang P., Yao Q., Sun Y. Electrospun fibers and their application in drug controlled release, biological dressings, tissue repair, and enzyme immobilization. Rcs advances. 2019; 9:25712–25729.

[8] Huanga Z., Zhang B., Kotaki C. A review on polymer nanofibers by electrospinning and their applications in nanocomposites composites. S cience and technology. 2003; 63:2223–2253.

[9] Quynh P., Sharma U. Electrospinning of polymeric nanofibers for tissue engineering applications: a review. tissue engineering. 2006; 12(5): 1197-1211.

[10] Goh V., Shakir I. Hussain R. Electrospun fibers for tissue engineering, drug delivery, and wound dressing. J.mater science. 2013;2(6): 1-18

[11] Elsdale T., Bard J., Collagen substrata for studies on cell behavior. Journal of cell biology. 1972; 54(3):626-637.

[12] Agarwal S., Wendorff h., Greiner A. Use of electrospinning technique for biomedical applications. Polymer. 2008; 49:5603-5621.

[13] Khan N. Applications of electrospun nanofibers in the biomedical field. Studies by undergraduate researchers at guelph. 2012; 5(2):64-73.

[14] Zhang Y., Venugopal J., Huang Z. Characterization of the surface biocompatibility of the electrospun pcl-collagen nanofibers using fibroblasts. Biomacromolecules. 2005; 6(5):2583-2589.

[15] Michiels C. Endothelial cell functions. Jourmnal of cellular biology. 2003; 196(3):430- 443

[16] Hashi K. Antithrombogenic modification of small diameter microfibrous vascular grafts. Arteriovascular thromb vasc boil. 2010; 30(8):1621-1638.

[17] Carlberg B., Zetterstrom M. Electrospun polyurethane scaffold for proliferation and neural differentiation of human embryotic stem cells. Biomed Mater. 2009; 4(4):45-68.

[18] Bing W., Mullins M., Cregg J. Creation of highly aligned Electrospun poly-l-lactic acid fibers for nerve regeneration applications. Journal of neural engineering. 2009; 6(1):16- 32.

[19] Peng F., Yu X., Wei M. In vitro cell performance on hydroxyapatite particles/ polylactic acid nanofibrous scaffold with an excellent particle along nanofiber alongation. Acta biolaterialia. 2011; 7(6):2585-92.

[20] Bianco A., Federico E., Cacciotti I. Electrospun poly (carpolactone) based composites using synthesized tricalcium phosphate. 2011; 22(12):1832-1841.

[21] Fang Q., Denglong C., Zhiming Y. In vitro and in vivo research on using anthreaea pernyi silk fibroin as tissue engineering tendon scaffolds. Sci eng. 2009; 29(5):1527- 1534.

[22] Xin X., Hussain M., Mao J. Continuing differentiation of human mesenchymal stem cells and induced chondrogenic and osteogenic lineages in Electrospun PLGA nanofiber scaffold. Bioamaterials. 2007; 28(2):316-325.

[23] Manchineella S., Thrivikraman G., Khanum K., Ramamurthy C. Pigmented silk nanofibrous composite for skeletal muscle tissue engineering. Adv. healthc. mater. 2016; 5:1222–1232.

[24] Basturk E., Demir S., Danis O. Covalent immobilization of polymerase onto thermyll crosslinked Electrospun PVA/PAA nanofibrous hybrid membranes. Journal of applied polymer science. 2012; 127(1):349-355.

[25] Sarthi M., Doraiswamy N., Pennathur G. Enhanced stability of immobilized keratinolytic rotease on Electrospun nanofibers. Preparative biochemistery and biotechnology. 2019; 49:695-703.

[26] William J., Cloete S., Hayward P. Degradation of proteins and starch by combined immobilization of protease and amylase galactoside on a single Electrospun nanofibrous membrane. Molecules. 2019; 24:508-519

[27] Isik C., Arabaci G. Synthesis and characterization of Electrospun PVA /Zn metal composite nanofibers for lipase immobilization with thermal, pH stabilities and reusability. Mater sci eng. 2019; 99: 1226-1235.

[28] Li J., Chen X., Xu D. Immobilization of horseradish peroxidase on Electrospun magnetic nanofibers for phenol removal. Ecotoxicol Environ Saf. 2019; 170:716-721.

[29] Haghju S., Bari M. Affecting parameters on fabrication of B-D- galactosidase immobilized chitosan /polyvinyl alcohol Electrospun nanofibers. Polymer. 2018; 200:137-143.

[30] Huang Y., Xie Z. Electrospinning of polymeric nanofibers for drug delivery applications. Journal of controlled release. 2014; 185:12-21.

[31] Thenmozhi S., Dharmaraj N., Kadirvelu K. Electrospun nanofibers: new generation materials for advanced applications. Materials science and engineering. 2017; 217:36- 48.

[32] Oh Y., Ju M., Kim Y. Adsorption of toluene on carbon nanofibers prepared by electro spinning. Science of the total environment. 2008; 393(2-3):341–347.

[33] Kang C., Pan Q. The investigation of Electrospun polymer nanofibers as a solid-phase extraction sorbent for the determination of trazodone in human plasma. Analytica chimica acta, 2007; 587(1):75–81.

[34] Pillay v., Dott c., Choonara y. A review of the effect of processing variables on the fabrication of electrospun nanofibers for drug delivery applications. Journal of nanomaterials. 2013:1-23.

[35] Ahn Y., Park S., Kim J. Development of high efficiency nanofiltersmade of nanofibers. Current applied physics. 2006; 6(6):1030–1035.

[36] Waters C., Noakes J., Pavery I, Hitomi C. US patent for liquid crystal devices 5088807. 1992.

[37] efficiency and low air resistance. Nanofibrous materials have also been studied for their excellent absorption and adsorption capability, and they might be used to absorb water and adsorb pollutants like toluene and benzene. Electrospun nanofibers have been utilised in electronics as anode materials in lithium ion batteries, tiny conducting fibres and magnetic materials, electronic micro- and nanodevices, and optical and electrical nanomaterials.