Biotechnology Advances 28 (2010) 325–347

Contents lists available at ScienceDirect

Biotechnology Advances

journal homepage: www.elsevier.com/locate/biotechadv

Research review paper

Electrospinning: A fascinating fiber fabrication technique

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ARTICLE INFO

Article history:
Received 15 March 2009
Received in revised form 17 September 2009
Accepted 8 January 2010
Available online 25 January 2010

Keywords:
Electrospinning
Nanofibers
Non-woven mats
Electric jet
Polymer solution
Solvents
Collector

ABSTRACT

With the emergence of nanotechnology, researchers become more interested in studying the unique properties of nanoscale materials. Electrospinning, an electrostatic fiber fabrication technique has evinced more interest and attention in recent years due to its versatility and potential for applications in diverse fields. The notable applications include in tissue engineering, biosensors, filtration, wound dressings, drug delivery, and enzyme immobilization. The nanoscale fibers are generated by the application of strong electric field on polymer solution or melt. The non-wovens nanofibrous mats produced by this technique mimics extracellular matrix components much closely as compared to the conventional techniques. The sub-micron range spun fibers produced by this process, offer various advantages like high surface area to volume ratio, tunable porosity and the ability to manipulate nanofiber composition in order to get desired properties and function. Over the years, more than 200 polymers have been electropun for various applications and the number is still increasing gradually with time. With these in perspectives, we aim to present in this review, an overview of the electrospinning technique with its promising advantages and potential applications. We have discussed the electrospinning theory, spinnable polymers, parameters (solution and processing), which significantly affect the fiber morphology, solvent properties and melt electrospinning (alternative to solution electrospinning). Finally, we have focused on varied applications of electrospun fibers in different fields and concluded with the future prospects of this efficient technology.

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doi:10.1016/j.biotechadv.2010.01.004

1. Introduction

Electrospinning, a broadly used technology for electrostatic fiber formation which utilizes electrical forces to produce polymer fibers with diameters ranging from 2 nm to several micrometers using polymer solutions of both natural and synthetic polymers has seen a tremendous increase in research and commercial attention over the past decade (Ahn et al., 2006; Lannutti et al., 2007; Hunley and Long, 2008; Reneker and Yarin, 2008). This process offers unique capabilities for producing novel natural nanofibers and fabrics with controllable pore structure (Zussman et al., 2003; He et al., 2005). Since the beginning of this century, researchers all over the world have been re-examining the electrospinning process (Cooley, 1902; Morton, 1902; Teo and Ramakrishna, 2006). This process of electrospinning has gained much attention in the last decade not only due to its versatility in spinning a wide variety of polymeric fibers but also due to its ability to consistently produce fibers in the submicron range consistently that is otherwise difficult to achieve by using standard mechanical fiber-spinning technologies techniques (Reneker et al., 2000; Schreuder-Gibson et al., 2002; Huang et al., 2003; Theron et al., 2005; Ma et al., 2005a). With smaller pores and higher surface area than regular fibers, electrospun fibers have been successfully applied in various fields, such as, nanocatalysis, tissue engineering scaffolds, protective clothing, filtration, biomedical, pharmaceutical, optical electronics, healthcare, biotechnology, defense and security, and environmental engineering (Luu et al., 2003; Subbiah et al., 2005; Ramakrishna et al., 2006; Cui et al., 2006; Wu et al., 2007; Barnes et al., 2007; Welle et al., 2007). Overall, this is a relatively robust and simple technique to produce nanofibers from a wide variety of polymers. Spun nanofibers also offer several advantages such as, an extremely high surface-to-volume ratio, tunable porosity, malleability to conform to a wide variety of sizes and shapes and the ability to control the nanofiber composition to achieve the desired results from its properties and functionality. Because of these advantages, electrospun nanofibers have been widely investigated in the past several years for its use in various applications, such as filtration, optical and chemical sensors, electrode materials and biological scaffolds (Liang et al., 2007). This technique has been known for over 60 years in the textile industry for manufacturing non-woven fiber fabrics. In recent years, there has been an increasing interest in exploiting this technology to produce nanoscale fibers, especially for the fabrication of the nanofibrous scaffold from a variety of natural and synthetic polymers for tissue engineering (Chong et al., 2007) such as polylactic acid (Yang et al., 2005), polyurethanes (Stankus et al., 2004), silk fibroin (Ohgo et al., 2003; Min et al., 2004a,b; Zarkoob et al., 2004; Alessandrino et al., 2008), collagen (Matthews et al., 2002), hyaluronic acid (Um et al., 2004), cellulose (Ma et al., 2005b), chitosan/collagen (Chen et al., 2007). Despite the several advantages offered by electrospinning, the throughput of nanofibers has been a serious bottleneck problem that limits their application. To increase the production rate of these spun fibers, a two-layer electrospinning system, with the lower layer being a ferromagnetic suspension and the upper layer a polymer solution and multiple spinnerets or nozzle systems arranged in a line/circle/matrix and a new bottom-up gas-jet electrospinning (bubble electrospinning) has been studied by various research groups (Yarin and Zussman, 2004; Theron et al., 2005; Tomaszewski and Szadkowski, 2005; Liu and He, 2007). The scale up of nanofibers through single jet is not very feasible and for various applications there is a requirement of large quantities of fibers. Various research groups have used porous hollow tube in order to get multiple jets and in this case the production rate can be enhanced by increasing the tube length and number of holes (Dosunmu et al., 2006; Varabhas et al., 2008). Apart from the huge success, advantages of electrospinning method and spun nanofibers there are still some challenges that need proper consideration. A major challenge encountered in using electrospun mats and scaffolds for tissue engineering is the non-uniform cellular distribution and lack of cellular migration in the scaffold with increasing depth under normal passive seeding conditions. The issue of cellular infiltration into the fiber architecture is rapidly gaining attention due to its potential in stagnating further applications of electrospun meshes or scaffolds in various tissue engineering applications. With the use of the conventional technique of electrospinning, nanofibers are obtained in a simple and inexpensive way. However, by this method over time there is a build-up of meshes with tremendous fiber density. It has also been reported that with the decrease of the electrospun fiber diameter there was an increase in the number of fiber-to-fiber contacts per unit length and a decrease in the mean pore radius in the mesh (Eichhorn and Sampson, 2005). Because of all these factors, there is a creation of a large size mismatch between the small pores in the structure and the larger