Chapter 3
Electrospinning:
Development and Biomedical Applications

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ABSTRACT

The goal of this chapter is to introduce the electrospinning technique - a materials processing technique that uses an electric field to draw a polymer solution into ultra-fine fibers. Further, this chapter aims to provide pertinent information to researchers who intend to use electrospinning in their research. The electrospinning technique was invented a few decades ago and has recently been adapted for biomedical applications. Electrospinning is now widely used in the biomedical field due in large part to its capability of fabricating ultra-fine fibers with unique physical and biological properties. In addition, electrospinning has gained popularity since the simplicity of setting up a fabrication apparatus and the ease of modifying the setup would allow researchers to produce various fibers with different properties in a relative short time. This chapter will review the electrospinning development, and discuss fabrication and characterization of electrospun fibers, and the current challenges and future directions of electrospinning.

INTRODUCTION

While there are various methods, such as melt-blowing (Ellison, Phatak, Giles, Macosko, & Bates, 2007), phase separation (Liu, & Ma, 2009), self-assembly (Hooseinkhani, Hosseinkhani, Tian, Kobayashi, & Tabata, 2006), and template synthesis (Tao, & Desai, 2007), available for fiber fabrication, electrospinning possesses many advantages over these fiber fabrication techniques. First, the setup for fiber fabrication is relatively simplistic and economical. Second, the setup can be easily modified to produce a variety of structures, such as non-woven (Li, Laurencin, Caterson, Twan, & Ko, 2002), aligned (Li, Mauck, Cooper, Uann, & Tuan, 2007), and core-shell fibrous scaffolds (Jiang, Hu, Li, Zhao, Zhu, & Chen, 2005). Third, the electrospinning process gives researchers the flexibility of using a great number of polymer selections to fabricate fibrous structures; many

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biodegradable, non-biodegradable, natural, and synthetic polymers have been successfully electrospun.

Electrospinning uses an electric field to draw polymer solutions into ultra-fine fibers with diameters ranging from a few nanometers to several micrometers. Fiber formation is controlled by the interactions between fabrication variables, such as voltage, the surrounding environment, and polymer solution property, and the variable combination determines the quality of as-spun fibers (Thompson, Chase, Yarin, & Reneker, 2007).

Due to the ultra-fine nature of the fibers, electrospun fibrous structures have a high porosity, high surface area-to-volume ratio (Li, 2002), and enhanced mechanical strength (Tan, Ng, & Lim, 2005). In addition, since structurally and morphologically similar to fibrous extracellular matrix proteins found in the body, electrospun fibers possess unique biologically-favorable properties (Li, Jiang, & Tuan, 2006). These properties can be tailored by selecting appropriate materials, electrospinning parameters, and fabrication setups, making electrospinning applicable to many research applications. For example, electrospun nanofibrous scaffolds have been used extensively in tissue engineering applications (Li, 2002; Prabhakaran, Venugopal, & Ramakrishna, 2009; Cui, Zhu, Yang, Li, & Jin, 2009). Similarly, medical implant fabrication has taken advantage of improved biological properties of electrospun fibers to promote tissue integration (Pinchuk, & Martin, 1988), enhance mechanical properties (Buchko, Shen, & Martin, 1999) and improve drug delivery (Smith, & Reneker, 2005). Finally, other applications, such as wound dressings (Chen, Cheng, & Chen, 2008) and biosensors (Sawicka, Gouma, & Simon, 2005) have employed electrospun fibrous structures to enhance their functionality.

The aims of this chapter are to introduce the electrospinning process and its current development, and to arouse readers' interest in developing new electrospinning applications in the biomedical field. In this chapter, the history and current development of the electrospinning technique will be outlined. We will then discuss the fabrication parameters that affect fiber formation and properties of electrospun fibers. This chapter will also provide an overview of the polymers currently used in electrospinning research and their applications in the biomedical field. Finally, the current challenges and future directions of using electrospinning will be discussed as well. We hope the information provided in this chapter will allow researchers to explore the possibilities of using electrospinning in their research.

HISTORY

The early work of Sir William Gilbert (1628) showed that a piece of charged amber could deform a droplet of water into a cone shape. His observations are the earliest accounts of the effect of electric charge on a solution. A solution affected by charge is the physical phenomenon that electrospinning is based on. Electrospraying is similar to electrospinning and it was first observed by Lord Rayleigh in 1882. In his work, he observed that as the electric charge applied to a liquid droplet increased, charge would built up on the surface of the droplet. The increased charge eventually created a sufficient force to split the droplet into smaller droplets (Rayleigh, 1882). After Rayleigh's findings, Zeleny (1914; 1917) performed experiments by charging an aqueous solution to mathematically describe the electrospraying mechanism, and obtained the first time-lapse photographs of the electrospraying process. In the following years, studies were focused on further optimizing the variables to improve the electrospraying of liquids (Vannegut and Neubauer, 1952; Drozin, 1954). Finally, Dole, Mack, and Hines' (1968) experiments of charging dilute polymer solutions led to the discovery of the electrospinning process.

The process of electrospinning is similar to electrospraying but uses electric charge to draw a viscous polymer solution into thin fibers rather

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