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Fast Vision of Two Electrospinning Techniques: History, Fundamentals and Applications

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Abstract

In recent decades the electrospinning technique has gained great interest in the scientific community. It is a simple and versatile technique that allows to obtain polymeric fibers at nanometric and micrometric scales. As a result of the process, two-dimensional and three-dimensional structures formed by fibers can be obtained, these materials have potential application in different industries such as textile, food and biopharmaceutical

Keywords: Electrospinning; Polymeric nanofibers; Drug delivery; Tissue engineering

Abbreviations: PLA: Polylactic Acid; PGA: Polyglycolic Acid

Introduction

Electrospinning is a technology for the production of continuous fibers in which high electrostatic forces are used to obtain them. The technique consists in that by increasing the potential difference that is created between two electrodes, one connected to the exit opening of the solution to be spun and another to the collector, the surface tension is overcome, causing the stretch of the drop and the consequent formation of fiber. During the process the drop generated at the tip of the needle is exposed to the action of a set of forces, the two main types are the electrostatic repulsive forces between the charges and the Coulomb force exerted by the external electric field. The action of these forces generate a distortion of the drop in conical shape denominated "Taylor cone". The solvent evaporates gradually during jet travel towards to the collector plate and the fibers are deposited in solid form [1-5].

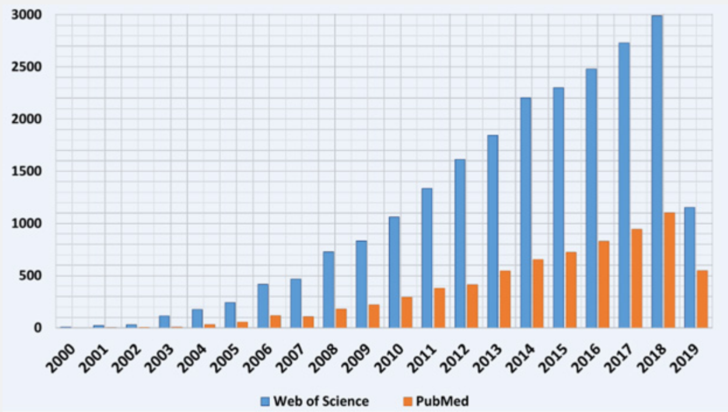

Figure 1: Number of publications per year using the expressions "electrospinning" over the last 20 years following Web of Science and PubMed.

The first reports of electrospinning in the literature date back more than a century when J.F. Cooley presented his patent "Apparatus for electrically dispersing fibers" in 1902. In 1914, John Zeleny conducted experiments on the output of liquid droplets at the end of a metallic capillary and from that he tried to establish a mathematical model for the behavior of fluids under electrostatic forces [1,6,7]. Subsequently, in the 1930s Anton Formhals made a significant contribution to the development of the technique. His first patenting registered in 1934 was the apparatus for the manufacture of yarns, using electric charges, reaching 22 patents associated with research and designs of electrospinning equipment in a period of 10 years. Between 1964 and 1969 Sir Geoffrey Ingram Taylor conducted studies about the effect of the application of an electric field on the formation of the polymer drop at the tip of the needle and demonstrated that a cone is formed from which the jet is generated. His demonstration allowed to establish the theoretical bases and the mathematical modeling of the electrospinning process. In the following years and up to the 1990s, very few works were carried out on this subject. In the early 1990s several research groups took up this line of work, especially the group of Reneker (University of Akron) which demonstrated the obtaining of fibers from a several polymers [3,6-9]. Since then, the publication of works on electrospinning has grown significantly per year as can be seen in the figure, in which the annual publications of two of the most recognized databases of the scientific literature are exposed.

A basic electrospinning equipment consists of four fundamental parts: a high-voltage source, a syringe with a metallic needle, a syringe infusion pump and a metal manifold that can be a flat plate or a rotating drum. Currently, there are two standard configurations of electrospinning, vertical and horizontal. The process can also be carried out using two independent syringes/needles with different solutions (Figure 2).

To adjust the diameter and the morphology of the fibers to be obtained, there are several parameters of the process to be taken into account. The parameters are grouped into three categories: properties of the polymer solution, processing conditions and environmental parameters. As regards the properties of the polymer solution, one of most important is the viscosity (depends mainly on the molecular weight and concentration of the polymer), also the surface tension and electrical conductivity of the solution, as well as the dielectric constant of the solvent. In the processing conditions, applied voltage, solution flow rate, collector type, needle diameter and distance from the needle to the collector influenced. The environmental parameters that most affect the process are temperature and humidity [1-5,10].

Biomedical application

The obtaining of materials with fibrous structure at micro/nanometric scale by the electrospinning technique has been very attractive for different applications. The simplicity of the process together with the possibility of scaling are ones of the main advantages. The micro/nanofibers have been applied in different fields such as microelectronics, environmental protection, catalyst design, energy and in the biomedical field which has been one of the most important application areas. Biomedical applications of fibrous matrices include tissue engineering, encapsulation and drug release, wound dressing, immobilization of enzymes, etc. [10-12].

In tissue engineering and/or wound dressings, the most interesting characteristics of these materials are those related to morphology. The submicrometric diameter of the matrices favors the existence of interconnected voids and that the surface area to volume ratio is high, which establishes a structure similar to the extracellular matrix, promoting good cell adhesion and proliferation. The main advantage of the electrospinning process for the encapsulation of drugs is the absence of heat, which can preserve the structure of temperature-sensitive molecules such as proteins and high efficiency in the encapsulation process of bioactive molecules can be achieved [2,4,10,12-14].

For the preparation of electrospinned fibers, almost 100 different polymers of both natural and synthetic origin have been used. Synthetic polymers allow better control over physical and chemical properties, but the in vivo compatibility is limited. Polyesters such as polycaproplactone, polylactic acid (PLA), polyglycolic acid (PGA) and its copolymers have been one of the most studied groups [15,16]. Other synthetic polymers that have also great acceptance are polyethylene glycol, polyvinyl alcohol, poly-N-isopropylacrylamide and polyurethane. In order to improve the biocompatibility and biodegradability of the fibers, numerous studies have been carried out using natural polymers. To date, fibers have been obtained from carbohydrates such as chitosan, cellulose, silk and proteins such as gelatin and collagen, among others [12,17].

Some examples of the matrices based on micro/nanofibers electrospinned and their biomedical applications, published in the last 5 years, are exposed in Table 1.

Table 1: Different polymers used to obtain micro/nanofibers by electrospinning and their applications.

Year	Polymers Used	Scale of fibers	Application	Source
2018	Poly-N-isopropylacrylamide/Eudragit L100-55	Micro and nanofibers	Drug delivery	Heyu Li et al.
2017	poly(di(ethylene glycol) methyl ether methacrylate)/ethyl cellulose	Nanofibers	Drug delivery	Heyu Li et al.
2018	polycaprolactone/chitosan and polycaprolactone/carboxymethyl chitosan	Nanofibers	Bone tissue engineering	Fereshteh Sharifi et al.

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2017	Gelatin	Nanofibers	Cartilage tissue engineering	Sheida Aliakbarshirazi et al.
2014	cellulose acetate/poly(vinyl pyrrolidone)	Nanofibers	Growing cells and Drug delivery	M.M.Castillo-Ortega et al.
2018	Hyaluronic acid / poly(vinyl alcohol) and 2-Hydroxypropyl-beta-cyclodextrin	Nanofibers	Wound dressing and Drug delivery	Morgane Séon-Lutz et al.
2019	Polyvinyl alcohol /Sodium alginate	Nanofibers	Wound dressing	Yadong Tang et al.
2016	Collagen/poly(lactic-co-glycolic acid) (PLGA)	Nanofibers	Guided tissue regeneration	Yufei Tang et al.
2015	Poly lactic-co-glycolic acid (PLGA) and gelatin	Nanofibers	Tissue engineering	Mohammad Mehrasa et al.
2019	Chitosan	Nanofibers	Wound dressing	Samaneh Bayat et al.

Conclusion

Electrospinning is a simple, versatile and cost-effective technique from which a wide variety of micro/nano structures can be manufactured. The adjustment of the parameters such as voltage, distance between the tip and the collector, viscosity and concentration of the solution, among others, allows to obtain easily arrays of micro/nano fibers electrospinned for the desired function. Electrospun nanofiber scaffolds/membranes have found numerous potential applications in almost all fields, including enzyme immobilization, sensory membranes, cosmetics, protective clothing, affinity membranes, tissue engineering scaffolds, drug delivery and wound healing applications.

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