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Functional electrospun nanofibrous scaffolds for biomedical applications

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Abstract

Functional nanofibrous scaffolds produced by electrospinning have great potential in many biomedical applications, such as tissue engineering, wound dressing, enzyme immobilization and drug (gene) delivery. For a specific successful application, the chemical, physical and biological properties of electrospun scaffolds should be adjusted to match the environment by using a combination of multi-component compositions and fabrication techniques where electrospinning has often become a pivotal tool. The property of the nanofibrous scaffold can be further improved with innovative development in electrospinning processes, such as two-component electrospinning and *in-situ* mixing electrospinning. Post modifications of electrospun membranes also provide effective means to render the electrospun scaffolds with controlled anisotropy and porosity. In this article, we review the materials, techniques and post modification methods to functionalize electrospun nanofibrous scaffolds suitable for biomedical applications.
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Keywords: Electrospinning; Nanofiber; Scaffold; Biomedical applications; Copolymers; Mixtures; Modifications

Contents

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1. Introduction

Electrospinning is a unique technology that can produce non-woven fibrous articles with fiber diameters ranging from tens of nanometers to microns, a size range that is otherwise difficult to access by conventional non-woven fiber fabrication techniques [1,2]. Electrospun nanofibrous scaffolds possess an extremely high surface-to-volume ratio, tunable porosity, and malleability to conform over a wide variety of sizes and shapes. In addition, the scaffold composition can be controlled to achieve desired properties and functionality. Due to these advantages, electrospun nanofibrous scaffolds have been widely investigated in the past several years with materials of different compositions [3–10] for applications of varying end-uses, such as filtration [11–13], optical and chemical sensors [14–19], electrode materials [20–23], and biological scaffolds [24–27].

For small-scale productions (i.e., on a laboratory scale), electrospinning is a simple method to generate nanoscale fibers. A basic electrospinning system usually consists of three major components: a high voltage power supply, a spinneret (e.g. a pipette tip) and a grounded collecting plate (usually a metal screen, plate, or rotating mandrel). When a charged polymer solution is fed through the spinneret under an external electric field, a suspended conical droplet is formed, whereby the surface tension of the droplet is in equilibrium with the electric field. When the applied electric field is strong enough to overcome the surface tension, a tiny jet is ejected from the surface of the droplet and drawn toward the collecting plate. During the jet propagation toward the collecting plate, the solvent in the jet stream gradually evaporates. The resulting product is a non-woven fibrous scaffold with a large surface area-to-volume ratio and a small pore size (in microns). The fiber thickness and morphology can be controlled by many parameters, such as solution properties (viscosity, elasticity, conductivity and surface tension), electric field strength, distance between the spinneret and the collecting plate, temperature and humidity. These parameters have been well studied and summarized in a recent review [28]. With very small fiber diameters, the yield per spinneret of the electrospinning process is extremely low. Recently, multi-jet electrospinning [29,30] and blowing-assisted electrospinning technology [30–32] have been developed, demonstrating the production capability for fabricating nanofibrous articles on an industrially relevant scale.

The usage of electrospun nanofibrous scaffolds for biomedical applications has attracted a great deal of attention in the past several years. For examples, nanofibrous scaffolds have been demonstrated as suitable substrates for tissue engineering [24–27], immobilized enzymes and catalyst [33–36], wound dressing [37,38] and artificial blood vessels [39,40]. They have also been used as barriers for the prevention of post-operative induced adhesion [41,42] and vehicles for controlled drug (gene) delivery [43–47]. For a successful application to a specific target, the nanofibrous scaffold must exhibit suitable physical and biological properties closely matching the desired requirements. For example, in tissue engineering, the electrospun scaffold should physically resemble the nanofibrous features of extracellular matrix (ECM) with suitable mechanical properties. It should also be able to promote cell adhesion, spreading and proliferation. For wound dressing, the nanofibrous scaffold should not only serve as a substrate for tissue regeneration, but also may deliver suitable bioactive agents, including drugs (e.g. antibiotic agent), within a controlled manner during healing. The fabrication of such functional nanofibrous scaffolds for biomedical applications often requires an interdisciplinary approach combining physics, chemistry, biology and engineering.

For electrospun nanofibrous scaffolds in biomedical applications, its physical and biological properties, such as hydrophilicity, mechanical modulus and strength, biodegradability, biocompatibility, and specific cell interactions, are largely determined by the materials' chemical compositions. Based on polymer physics, copolymerization and polymer blending are two effective means to combine different polymers to yield new materials properties. Thus, by selecting a combination of proper components and by adjusting the component ratio, properties of electrospun scaffolds can be tailored with desired new functions. For example, many kinds of copolymers and polymer mixtures, such as poly(lactide-co-glycolide) [41], poly(ethylene-co-vinyl alcohol) [48], mixtures of collagen with elastin [49], and mixtures of chitosan with poly(ethylene oxide) (PEO or PEG when the molecular weight is small, say less than 5000 Da) [50], have been electrospun to fabricate nanofibrous scaffolds for biomedical applications, but with varying degrees of success.

Besides taking advantage of the materials compositions, the fabrication process, through which the fiber diameter, morphology and scaffold porosity can be manipulated, also plays an important role on the scaffold property and functionality. For example, the two-phase electrospinning process provides a new pathway to incorporate drugs or biopolymers inside the fiber core that will be suitable for the controlled release over a prolonged period of time [51]. Physical and chemical modifications of the scaffolds after electrospinning are also able to render the scaffolds with enhanced properties and suitable functionality for specific applications. For example, the grafting of gelatin

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