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Effect of collector design on the morphological properties of polycaprolactone electrospun fibers

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ABSTRACT

Polycaprolactone (PCL) fibers were produced by electrospinning using three collectors: rotating drum, static copper wires, and a rotating mandrel. The effect of collector design on the alignment and morphology of fibers was evaluated. The drum collector produced a typical tridimensional structure whereby the rotational speed mechanically stretches fibers and affects their diameter and alignment. Randomly oriented fibers with an average diameter of 1142 ± 391 nm were obtained at 0 rpm, while aligned fibers with an average diameter of 663 ± 334 nm were produced at 2000 rpm. Static copper wires produced a novel fiber pattern in which the degree of orientation of the fibers is related to the electrical field distribution along the collector. The best fiber alignment and lowest average fiber diameter (490 ± 131 nm) were obtained using parallel copper wires with a gap of 1 cm. Two main forces influenced the fibers produced by the rotating mandrel. First, the attraction of the electrical field by the collector induced the deposition of fibers parallel to its axis with an average diameter of 606 ± 329 nm. Second, the stretching force from the high-speed rotation induced the deposition of fused fibers transverse to the collector axis.

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1. Introduction

Electrospinning is a versatile technique used to produce micron and submicron fibers from a wide range of polymers. Using this technique, fiber formation starts when an electrical field is generated on the surface of a polymeric solution and the electrical potential force overcomes the surface tension of the solution, thereby changing the spherical drop to a conical shape, an effect known as the Taylor cone. Electrically charged jets arise from the tip of the cone. Then electrostatic forces create a curled and chaotic movement, or bending instability, driving the jets to the collector. Meanwhile, continuous nanofiber elongation and solidification take place, yielding interconnected fibrous structures with high porosity and expanded surface area [1,2]. Therefore, collector characteristics strongly influence the electrical field and, consequently, the architectural deposition of the electrospun fibers [3–7].

PCL is a synthetic and resorbable polyester with excellent biocompatibility. Because of these characteristics, this polymer has been widely applied to produced new electrospun scaffolds for tissue engineering [8]. This letter aims to demonstrate the effect(s) of collector design on patterns of PCL micro and nanofibers. Different collector configurations based on conductive wires, rotating drum and mandrel were explored. The effect(s) of collector design on the electrical field and its resultant impact on fiber architecture was discussed.

2. Experimental

2.1. Materials

Polycaprolactone (PCL) 80 kDa and solvents were purchased from Sigma Aldrich Co. (St. Louis, MO, USA).

2.2. Preparation of electrospun fibers

Micro and nanofibers were produced with a typical electrospinning equipment with three distinct metallic collectors: a rotating drum, 6 mm grounded parallel copper wires, and 1 mm rotating mandrel (see Supplementary Material, Fig. S1). Electrospinning solutions were obtained by dissolving PCL 10% (w/v) in a blend of chloroform: dichloromethane: dimethylformamide (6: 3: 1, v/v/v). Electrospinning parameters were set as follows: solution flow rate of 1 mL/h, voltage 15 kV, and needle to collector distance of 10 cm. All protocols were performed under controlled conditions, i.e., relative humidity = 50 ± 10% and temperature = 20 ± 2 °C.

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2.3. Characterization of electrospun fibers

Electrospun mats were analyzed through scanning electron microscopy (SEM, Hitachi S4100) at an accelerating voltage of 10 or 15 kV. Fiber alignment and average diameters were calculated from 100 measurements per image from three experiments using Image J software (Image J 1.37c, Wayne Rasband, National Institutes of Health, USA).

2.4. Statistical analyses

All data were compared by one-way ANOVA, followed by post hoc test. $P < 0.05$ was considered statistically significant.

3. Results and discussion

Fibers deposited on the surface of the drum collector formed a typical layer-by-layer 3D structure. Fig. 1 shows the impact of rotation on PCL fiber characteristics. For a static drum, randomly oriented fibers with an average diameter of 1142 ± 391 nm were obtained. Increasing the rotation speed to 2000 rpm caused a significant decrease in the mean fiber diameter to 663 ± 334 nm. This decrease is related to the stretching force caused by high rotation during fiber deposition on the collector. Also, narrower fiber diameter distributions were obtained, and more than 75% of fibers presented less than 20 degrees of alignment deviation in relation to the zero angle. The chaotic motion of the charged jets and the aerodynamic drag forces from the collector at high speed, however, hamper the formation of a perfectly aligned structure [7].

A similar fiber alignment pattern was obtained using parallel copper wires with a gap of 1 cm. The parallel wires directed the electrified jets toward a specific direction and yielded aligned nanofibers with an average diameter of 490 ± 131 nm. This represented a significant decrease relative to fibers obtained from the drum collector, as well as narrower fiber diameter distribution (Fig. 2). Similar to the rotating drum (set at 2000 rpm), more than 75% of fibers presented less than 20 degrees of alignment deviation

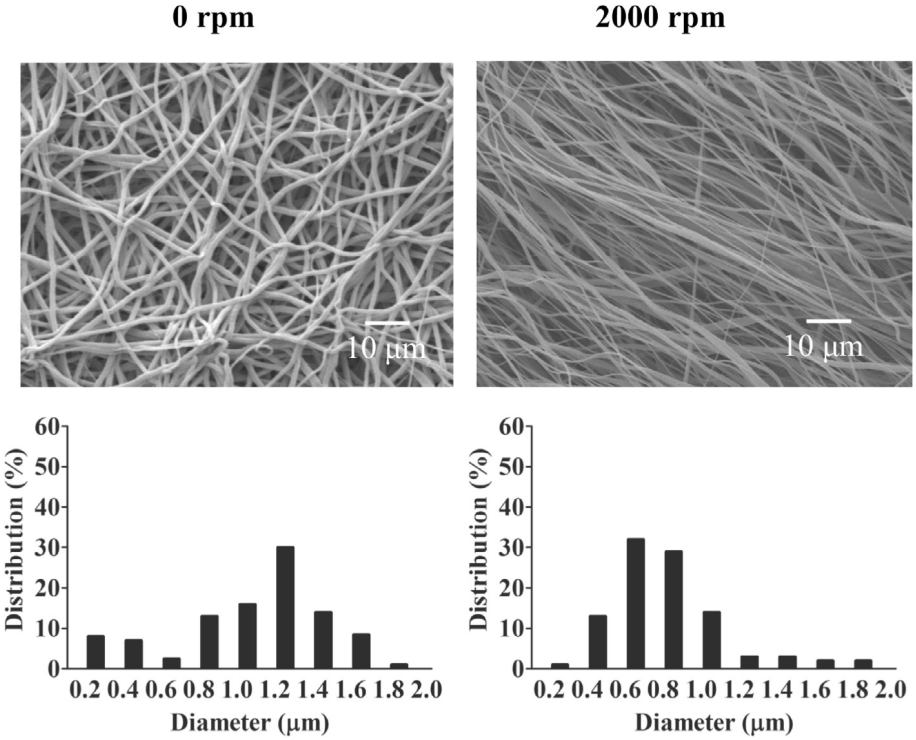

Fig. 1. SEM images and their respective fiber diameter distribution, showing the effect of rotational speed on the characteristics of fibers collected on the rotating drum.

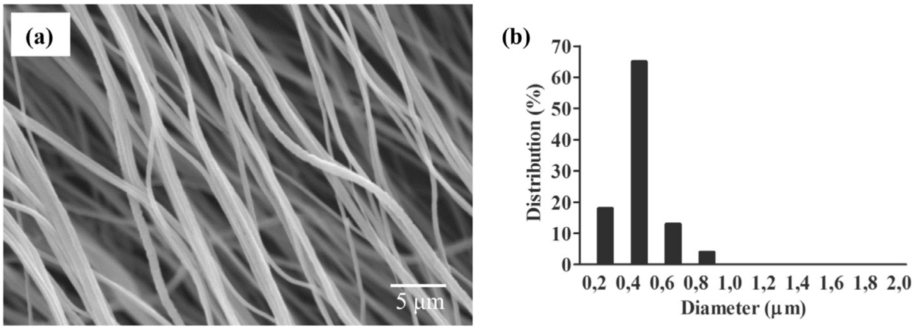

Fig. 2. SEM image (a) and its respective fiber diameter distribution (b), showing the first layers of fibers deposited on the parallel copper wires collector (gap = 1 cm).

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