A METHOD FOR JET STABILITY AND FIBER ALIGNMENT DURING ELECTROSPINNING PROCESSES

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Introduction

Electrospinning is the formation of micron to submicron polymer fibers from an electrostatically driven jet of polymer solution. It is a relatively simple process developed decades ago, but in recent years it has experienced a growth in interest from the engineering community. The applications of electrospun materials in nanotechnology include fibers for drug delivery, tissue engineering, chemical sensing, membrane-based filtration, and many others [1]. One strong advantage of these fibers is the large surface area to volume ratio [2]. In various applications of nano-sized fibers, controlled direction of fiber alignment can be advantageous; in one such case, alignment of fibers is critical for directing neurite outgrowth for neural tissue engineering [3]. Not every cell type grows efficiently in a randomly orientated matrix, which makes fiber alignment a crucial subject of study, especially in tissue engineering.

One of the basic techniques for fiber alignment is to utilize a rotating drum for fiber collection. This method, however, requires that the velocity of the rotating drum matches the velocity of the polymer jet; too slow, and the fiber will accumulate, and too fast, and it will stretch or break the fiber [1, 5]. Experiments including auxiliary electrodes together with a rotating collector show the possibility of coercing a fiber directionally based on electrode orientation during the collection process [5]. Further techniques exploit the use of electrostatics to dampen the random motion of the polymer jet; thereby increasing the probability of determining fiber position [4]. The aforementioned techniques work, but are limited to uniaxially-aligned fibers. Increasing fiber control past uniaxial fibers will increase the usability of nano-fiber scaffolds.

Our work demonstrates the combined use of previous techniques to dampen instabilities and align fibers through the employment of electrostatic lens elements and rotating collection surfaces. We are currently extending the work to control fiber deposition in the transverse direction through dynamic control of the external electric field.

Materials and Methods

Poly (ethylene oxide) was chosen in this study for its biocompatibility and its ease of use in electrospinning; a solution of 5 wt% PEO (average MW ~400,000, powder, Sigma Aldrich) was mixed in water. An electrospinning configuration was developed based on a combination of proven techniques [1, 4, 5] to align PEO fibers on a rotating surface as shown in figure 1. The concentric lens element consists on 8 copper rings of 4.5 in. diameter with a thickness of 0.25 in. and 0.5 in. between rings. Two high-voltage power supplies (Gamma High Voltage Research) were used to apply the required charge of +8KV and +5KV on the needle tip and the concentric lens elements respectively. A third power supply (Glassman High Voltage) was used to provide a charge of -11KV on the collection surface. The PEO solution was fed through a glass syringe and 18 gauge blunt tip needle using a syringe pump. A rotating collection device operates with a DC motor at 3000 – 11600 RPM perpendicular to the polymer jet.

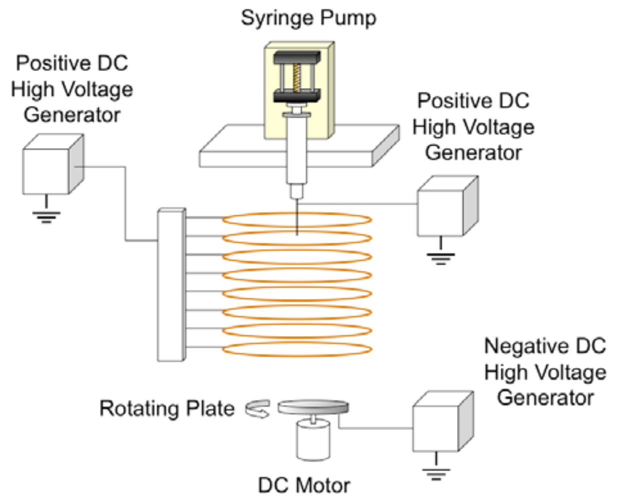

Figure 1: Schematic Illustration of electrospinning setup

As the polymer solution is pushed through the syringe needle, the voltage potential pulls the fiber jet towards the rotating collection plate. The concentric lens element dampens the fiber whipping motion to almost a straight line further increasing our overall control. The revolving disk is positioned offset to the center of the lens elements to maximize the linear velocity of the collection region.

Results and Discussion

Aligned fibers were collected with the current experimental device. The effects of rotation speed of the collector were studied at 8200, 10500, and 11600 RPM and at a distance of 14.5 cm from the needle tip. The collection of fibers on the rotating collector plate was in the shape of a ring with a thickness of 0.75 cm to 0.85 cm. Scanning Electron Microscope (SEM) images were taken in three spots on each ring-shaped sample; at the inner edge, in the center, and at the outer edge. Greater speeds are obtained further from the center of rotation, and the three images allow us to study the effect of linear speed of collection region on fiber alignment. Fig. 2 shows an example of SEM images taken from a non-aligned, and an aligned sample using the current configuration at different speeds. These results illustrate that a speed in the order of 3 m/s is sufficient for fiber alignment.

A histogram was created from angle measurements normalized to the length of the fiber in pixels. This technique allows for quantification of fiber alignment under several conditions, thereby allowing for an optimization study of the different parameters for electrospinning, and their influence on fiber alignment. Further analysis of the SEM images was performed to determine the effect of the concentric lens element in obtaining uniform fiber diameter on the collected sample, which is also of critical importance in tissue engineering studies.

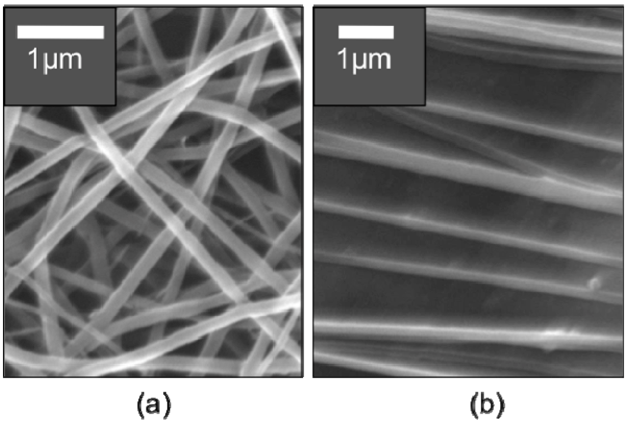

Fig. 2: SEM images for electrospun PEO scaffolds for collector plate velocities of (a) 0 m/s and (b) 2.7 m/s.

Conclusion

Results presented here demonstrate the capabilities of the current experimental system to produce uniaxially aligned fibers with uniform diameter. Work is underway to use additional electrodes to control the fiber deposition in the transverse direction. The goal is to oscillate the fiber with auxiliary electrodes just before contact with the rotating surface to produce controlled, multi-directional fiber alignment. Ongoing work consists in determining the optimal parameters to obtain aligned scaffolds of uniform fiber diameter using different polymers.

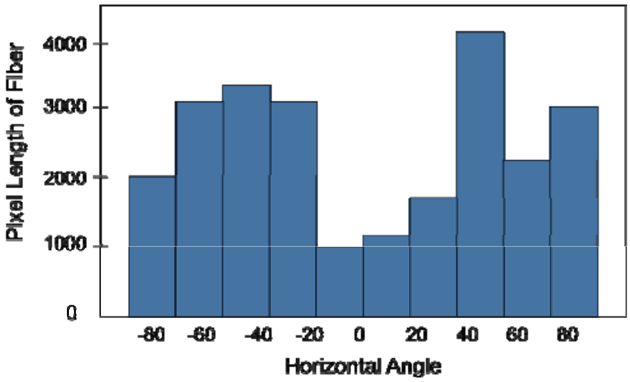

Fig. 3: Histogram of fiber length vs. horizontal angle of electrospun PEO with a collector plate velocity of 0 m/s.

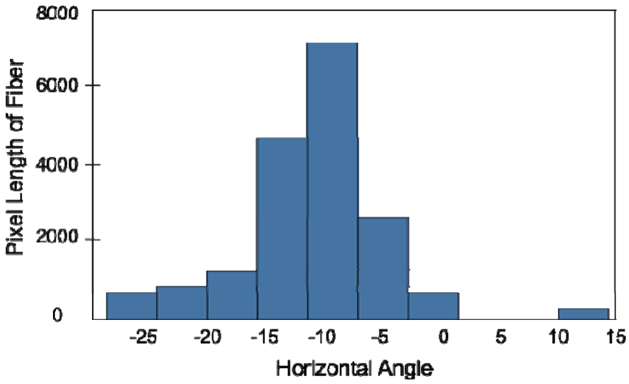

Fig. 4: Histogram of fiber length vs. horizontal angle of electrospun PEO with a collector plate velocity of 2.7 m/s.

References

1. Wu, Y, Carnell, L.A. and Clark, R.L. Control of electrospun mat width through the use of parallel auxiliary electrodes. *Polymer* 48 (2007) 5653-5661
2. Huang, Z., Zhang, Y.Z., Kotaki, M. and Ramakrishna S. A review on polymer nanofibers by electrospinning and their applications in nanocomposites. *Comp Sci and Tech* 63 (2003) 2223-2253
3. Wang, H.B., Mullins, M.E., Cregg, J.M., Hurtado, A., Oudega, M., Trombley, M.T. and Gilbert, R.J. Creation of highly aligned electrospun poly-L-lactic acid fibers for nerve regeneration applications. *J of Neural Eng* 6 (2009) 1741-2560
4. Deitzel, J.M., Kleinmeyer, J.D., Hirvonen, J.K. and Beck Tan, N.C. Controlled deposition of electrospun PEO fibers. *Polymer* 42 (2001) 8163-8170
5. Carnell, L.S., Siochi, E.J., Wincheski, R.A., Holloway, N.M. and Clark, R.L. Electric field effects on fiber alignment using an auxiliary electrode during electrospinning. *Scripta Materialia* 60 (2009) 359-361