Nanofibrous Membranes Consisting of Aligned Fibers and Multilayered Structures for Tissue Engineering Applications

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Introduction

Electrospinning is regarded as a versatile process for fabricating nanofibers and has attracted much attention recently for producing fibrous tissue engineering scaffolds (Ramakrishna S, et al., An Introduction to Electrospinning and Nanofibers, 2005, World Scientific). In most cases, these scaffolds are fiber meshes without fiber alignment. For some particular tissue engineering applications, fibrous membranes made of aligned nanofibers may be desired. Therefore, the electrospinning of aligned fibers of a natural, biodegradable and relatively inexpensive polymer, poly (hydroxybutyrate-co-hydroxyvalerate) (PHBV), was investigated.

Materials and Methods

The PHBV used (M_w = 310,000, 2.9 mol% of hydroxyvalerate) was commercially available. A PHBV solution (using chloroform as the solvent) of 15wt% polymer concentration was prepared. The previously used electrospinning setup (Tong HW and Wang M, Key Engg Mater, 2006; Vol.334-335: in press) for producing PHBV fiber meshes was modified in order to fabricate aligned fiber mats. The solution feeding rate was 1 ml/h and the electrospinning voltage was 25 kV.

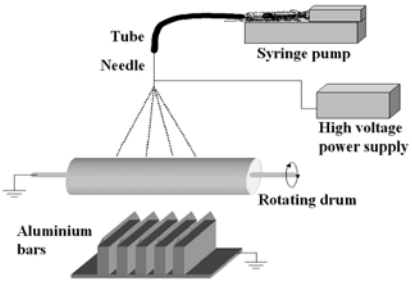

Figure 1. The electrospinning setup for aligned fibers

In the current setup (Fig.1), a rotating drum (Φ40 mm) covered with an Al foil was placed 10 cm below the needle tip. A set of knife-edged Al bars were placed under the drum. Both the drum and the bars were grounded. During operation, a PHBV jet was ejected from the needle onto the rotating drum. Due to solvent evaporation along its trajectory in air, the jet solidified into a fiber before reaching the drum and finally formed a circumferentially aligned fibrous membrane on the drum. By varying the direction of the Al foil, aligned fibrous membranes could be stacked into multilayered structures with each layer having a different direction of fiber alignment. Electrospun PHBV samples produced were analyzed using SEM and other techniques.

Results and Discussion

At low rotational speeds of the drum (<500 rpm), only randomly oriented fibers were collected (Fig.2a). Above 500 rpm, the fiber could be taken up quickly by the rotating drum in a circumferential direction and thus aligned fibers were obtained. The degree of fiber alignment improved as the rotational speed increased (Fig.2b and 2c). At 3000 rpm, nearly 80% of electrospun fibers aligned at angles between 89° and 94° relative to the longitudinal axis of the drum (Fig.3). Optimizing the rotational speed is important for generating fibers with the best alignment, which may be desirable for some applications as cells tended to proliferate in the fiber direction (Xu CY, Biomaterials, 2004;25:877-886).

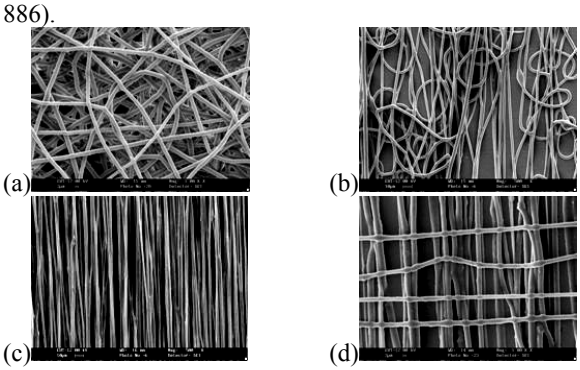

Figure 2. Electrospun PHBV fibers collected at different rotational speeds: (a) 100 rpm, (b) 625 rpm, (c) 3000 rpm, (d) 3000 rpm, with a double-layer structure

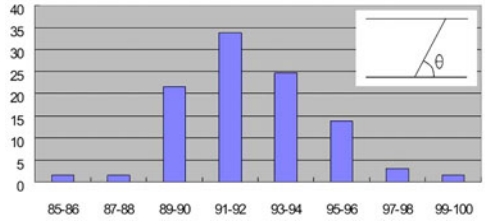

Figure 3. Degree of alignment as measured from Fig.2c

Electrospun aligned fibers could also be obtained by using a pair of parallel electrodes or a rotating disk with a sharp edge. But with these techniques, only small-size fibrous membranes can be produced. Although using a rotating drum alone could collect aligned fibers in a large area, the degree of alignment is usually unsatisfactory. In this study, the rotating drum was accompanied by knife-edged conductive bars, which resulted in well-aligned fibers covering a large area. It was also shown that multilayered structures consisting of aligned electospun fibers (Fig.2d) could be made in a very simple process. Both the method of producing the aligned, layered fibrous structure and the structures produced can be important for the engineering of some human body tissues.

Conclusions

A technique has been established to produce large-size fibrous membranes of aligned PHBV fibers through electrospinning. The technique allows the fabrication of aligned, layered fibrous structure in a simple and efficient manner. The membranes of aligned PHBV nanofibers and the aligned, layered fibrous PHBV structures produced can be suitable for some tissue engineering applications.