Development of Core-Sheath Nanofibers for Soft Tissue Engineering via Co-axial Electrospinning

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Statement of Purpose:

In recent years, electrospun nanofiber structures, using natural or synthetic biodegradable polymers, have drawn increased interest for use as scaffolds for tissue engineering. Electrospun nonwoven webs serve as near ideal substrates to grow soft tissues in that they provide a unique structure characterized by a high surface area to volume ratio and three-dimensional interconnected pore network, both of which enhance cell attachment and proliferation[1]. Additionally, it is widely accepted that the electrospinning technique makes it possible to generate structures that resemble native extra-cellular matrix (ECM) elements[2].

The primary reason for using natural polymers, (e.g.collagen), is that they are inherently capable of binding cells since they carry specific protein sequences such as RGD[3]. Synthetic biodegradable polymers, on the other hand, provide the necessary mechanical properties, such as viscoelasticity and strength, and their degradation rate can be controlled precisely as needed[4]. However, the use of either a natural polymer or a synthetic polymer alone, limits the range of properties that can be obtained from the structure. Therefore, combining natural and synthetic polymers to produce bicomponent nano-size structures that have novel hybrid properties at the sub-micron level has the advantage of increasing potential applications of nanofiber structures for tissue engineering.

Methods:

The approach adopted to achieve the goal involves ‘co-axial electrospinning’ of two different biodegradable polymers, one natural and the other synthetic, to produce ‘sheath-core’ structures. A special type of co-axial needle set-up has been prepared as proposed by Loscertales et al[5].

Initial study to determine the feasibility of the approach to develop bicomponent structures has been performed using polyvinyl alcohol (PVA) and polyethylene oxide (PEO) as sheath and core respectively. 17% (wt/vol) solution of PVA and 10 % (wt/vol) solution of PEO in deionized water were used. In this study, the particular role of the applied voltage in core-sheath fiber formation was investigated. Evidence of bi-component structure formation was acquired by means of morphological analysis using transmission and scanning electron microscopy techniques.

The ongoing work involves the co-axial electrospinning of materials suitable for tissue engineering (i.e. collagen and polycaprolactone (PCL) as sheath and core respectively). It is hypothesized that the collagen sheath will aid in cell adhesion and proliferation whereas the PCL core will impart strength and elasticity over an extended period. After initiating cell growth, collagen will biodegrade exposing the PCL core, which will provide mechanical and dimensional stability to the tissue construct as it continues to proliferate prior to implantation.

Results / Discussion:

During the co-axial electrospinning experiments, it was observed that the applied voltage is very critical in forming the core-sheath fibers. Too low a voltage causes the solutions to drip and no fiber formation occurs. At a critical voltage, both the solutions form Taylor cones and a co-axial composite jet emerges from the vertex of the outer (sheath) Taylor cone. If, on the other hand, the voltage exceeds this critical value, separate diverging jets originate from the two solutions and no core-sheath structure is obtained. With the PVA and PEO solutions, the critical voltage of 17kV was found to form a co-axial jet and hence the desired core-sheath structure.

Characterization of the electrospun mats, obtained in the preliminary study, was performed using electron microscopy techniques. The morphology was examined under SEM and the cross-sections of the fibers were observed under TEM. The results of the initial study are shown in Figure 1. The micrographs clearly reveal the core-sheath morphology in the electrospun nanofibers.

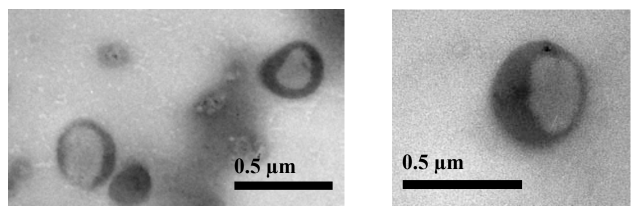

Figure 1: TEM Cross-sections of PVA-PEO (Sheath-Core) Bicomponent Fibers

Conclusions:

This preliminary study has demonstrated the feasibility of the co-axial electrospinning approach. The results have indicated that the applied voltage is very critical to core-sheath nanofiber formation. It is believed that the proposed approach can be successfully adopted to develop core-sheath nanofibers using collagen and PCL.

Future Studies:

Actual cell culture studies using human mesenchymal stem cells will be performed to evaluate viability of collagen-PCL bicomponent structures for engineering soft tissues such as cartilage and blood vessels. From the knowledge gained, it is hoped, we shall identify scaffold parameters (fiber composition and size & scaffold porosity and thickness) that will be optimum for culturing these diverse cell lines as well as for implant development.

References:

1. Yashimoto *et al.*, Biomaterials 2003;24(12):2077-2082.
2. Wnek *et al*., Nano Letters 2003;3(2):213-216.
3. Boland *et al*., Frontiers in Bioscience 2004;9:1422-1432.
4. Hakkarainen, Adv. Polym. Sci. 2002;157:113-138.
5. Loscertales *et al*., Science 2002;295:1695-1698.