A Simple Template to Align Electrospun Fibers in a User-Defined Manner

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Statement of Purpose: It is our overall goal to design a cell-seeded scaffold with distinct regions that support heterogeneous expression of collagen I and II. Central to achieving this goal is the design of multi-phasic meshes with distinct, yet continuous, fiber architectures in each region. Electrospinning is a simple and versatile technique that has garnered widespread interest due to the ability to create complex mesh architectures (Li WJ *et al*. J Biomed Mater Res. 2002; 60(4):613-621; Srouji S *et al*. J Mater Sci: Mater Med. 2008; 19:1249-1255). Electrospun fibers are collected onto a surface which can be specifically designed to align meshes in a user-defined manner (Teo WE and Ramakrishna S. Nanotechnology. 2006;17:89-106).

Described herein is a technique to manufacture patterned electrospinning templates which facilitate collection of electrospun meshes aligned in a controlled manner. In the current study, we describe how the template is made and the influence that fiber architecture has on mesh mechanical properties. With this template manufacturing technique, a multi-phasic electrospun scaffold is possible in future studies.

Methods: The polymer used in this study was a custom-designed aliphatic polyurethane based on 1,4-butane diisocyanate , polycaprolactone diol and 1,4-butanediol in a 4/1/3 molar ratio. Final polymer M_w was 39.7 kDa.

Templates consisted of phenolic boards with inlaid copper traces. All supplies were acquired from MG Chemicals (Surrey, British Columbia). Architecture designs were created with computer aided design software (ExpressPCB, Santa Barbara, CA), then transferred and etched from pre-sensitized copper-clad boards. Four template designs were made (Figure 1).

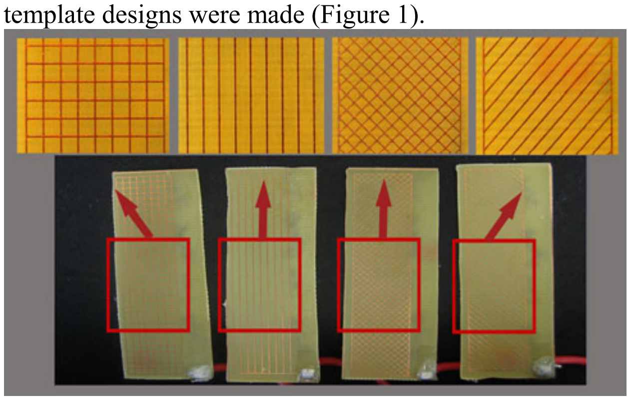

Figure 1. Templates: cross, parallel, diamond, and angle

Fiber alignment and mechanical properties of each architecture was assessed. Alignment was measured with a two-dimensional fast Fourier transform (2D FFT) approach on microscopy images of electrospun meshes (Ayres CE *et al*. J Biomater Sci Polymer Edn. 2008; 19(5):603-621). Subset image samples were taken from regions of fibers that laid over traces as well as regions between traces. Meshes were subject to a tensile test according to ASTM standard D5035. Modulus of elasticity and inflection strain, the transition point between the toe and linear regions of the stress-strain curve, was computed for all architectures.

Results: With a trace width of 0.15 mm, fibers were observed to align along and aggregate onto template traces (Figure 2). For all template architectures, FFT analysis revealed distinct peaks at 90° and 270° indicating alignment of fibers parallel to traces. Fibers between traces exhibited peaks of near uniform height that occured at approximately 90° periodicity. Ayres *et al.* refer to this pattern as a "hallmark" of random fibers in a mesh.

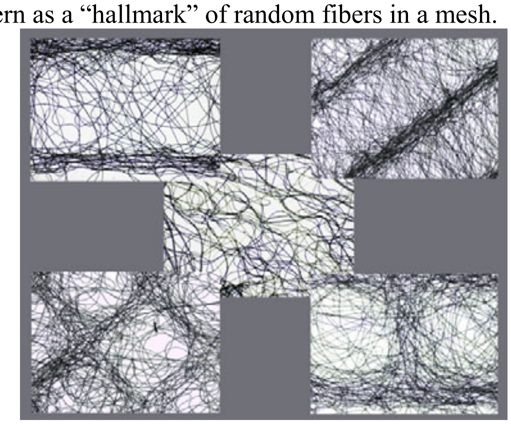

Figure 2. Clockwise from upper left: parallel, angle, diamond, and cross meshes. Center is a random mesh. All images collect at 4X.

The mean inflection strains for parallel, angle, diamond, and cross architectures were 0.49, 0.58, 1.16 and 0.39 %, respectively, with a significant difference between diamond and all other architectures. At low strains, fibers in the diamond architecture undergo a re-organization aligning along the principal strain direction. During re-organization the fibers gradually align to resist tension. In contrast, fibers in the other architectures immediately resist tension given their predominant fiber orientation. The mean moduli for parallel, angle, diamond, and cross architectures were 8.21, 8.61, 9.93 and 9.88 MPa, respectively.

Conclusions: A straightforward and inexpensive technique is presented which can be used to obtain electrospun meshes aligned in a controlled manner. This technique incorporates the precision of CAD design into the electrospinning process. Template design can be manipulated to modulate mechanical behavior of electrospun scaffolds. Subsequent studies will employ this template manufacturing technique to create scaffolds capable of delivering both tensile and compressive oriented strains in a multi-phasic cell-seeded tissue engineering construct.