

INCORPORATION OF FIBER TORTUOSITY EFFECTS IN A CONSTITUTIVE MODEL FOR ELECTROSPUN SCAFFOLDS

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Synthetic scaffolds for tissue engineering applications require mechanical properties comparable to the native tissue for at least the minimum time necessary for the seeded cells to lay down an equivalent supporting matrix. To achieve maximal results in the scaffold design process, it is beneficial to know and control specific scaffold characteristics that may alter the mechanical properties of the scaffolds so that a minimal amount of parameters could be changed to achieve the characteristics of the desired scaffold. One familiar characteristic in electrospun scaffolds is fiber tortuosity, which is analogous to collagen crimp in soft tissues. A constitutive model that incorporates the effect of this scaffold characteristic, and that can predict the response of the scaffold without having to perform time-consuming mechanical tests, would assist in the design of the scaffold and allow for more expediently-designed and predictable custom-tailored scaffolds. Currently we are measuring the effects of fiber tortuosity on the mechanical response of the scaffolds. We are also developing a constitutive model that is dependent not only on fiber angle but also on the fiber tortuosity with respect to fiber angle. Tortuosity measures were performed on SEM images of all unstrained scaffolds by tracking a fiber for the viewable length of the fiber (Fig. 1a). Tortuosity is calculated as the full length of the fiber divided by the end-to-end distance. Twenty-five fibers were tracked on each SEM image for a total of 150 fibers for each spin speed. To better understand the change in tortuosity as the scaffolds undergo deformations, a stage was designed that allowed the scaffold to be stretched and imaged using SEM (Fig 1b). Specific regions of the scaffolds were imaged in a nonstretched reference state and at various levels of strain.

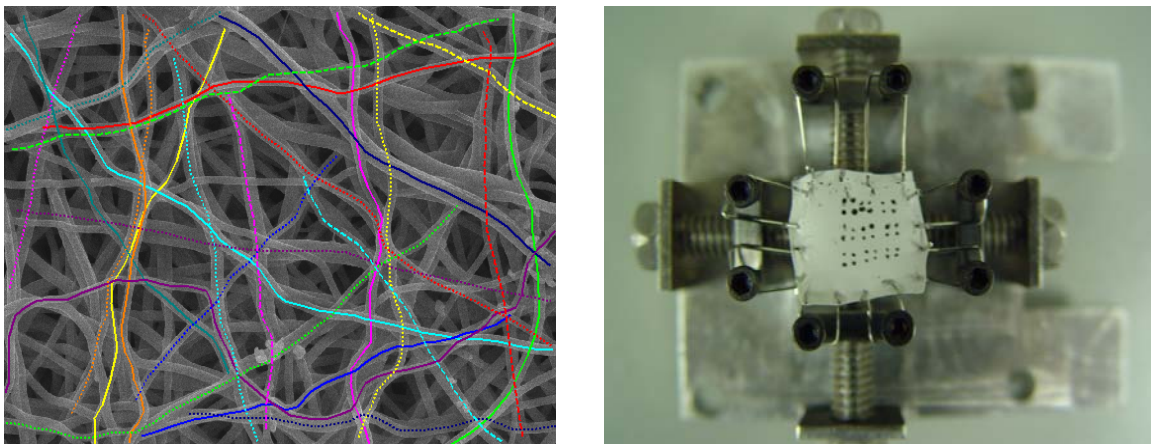


Figure 1. (a) Tracking of fibers to determine the degree of tortuosity with respect to angle, (b) Stage to allow for the acquisition of SEM images of strained scaffolds

Structural Model

The resulting fiber orientation data were determined from the SEM data. The PEUU effective fiber stress-strain properties were determined from the mechanical data. The fiber recruitment, $D(x,\theta)$, is a function of the fiber strain and orientation θ , with the strain itself a function of fiber angle, since it was found that tortuosity varies with angle as the mandrel speed increases. The structural and mechanical data will then be combined to determine the Lagrangian membrane stresses. Using the structural data, $R(\theta)$, and a single equibiaxial test for the determination of the fiber stress-strain response, the model allows one to predict the complete biaxial mechanical response of the polymer. The PEUU scaffolds displayed higher orientation with increasing stretch as tortuosity is gradually lessened. Tortuosity was higher in the direction of spin of the mandrel. The scaffolds with the most amount of variation in tortuosity were those developed at higher mandrel velocities. Tortuosity for random (isotropic) scaffolds exhibited no dependence on fiber angle. As the mandrel speed was increased though, tortuosity was much more dependent on fiber angle. Inclusion of the tortuosity data into the constitutive model yielded a much more robust fit to the experimental data. Upon stretching the scaffolds and viewing them under the SEM, it was seen that the fibers gradually straightened. The disappearance of tortuosity depended on the scaffold, which showed angular dependence, and also the amount of stretch. This is the first time that this angular dependence has been incorporated into a structural model developed for soft tissues or scaffolds. Future work will investigate the effect of stretch on cells integrated into the scaffold and compare this with cellular deformation within the ECM.