Micromechanical Deformations of Electrospun Elastomeric Scaffolds for Tissue Engineering

Todd Courtney, John Stella, Jun Liao, William Wagner, Michael Sacks
University of Pittsburgh, Pittsburgh, PA

Introduction

Most elastomeric scaffolds for tissue engineering applications are complex networks of fibers whose architectures (fiber orientation, tortuosity, pore size, etc.) change dramatically under applied force. Cells seeded within and on the surface of these scaffolds witness these changing architectures as the scaffolds are strained. It is thus beneficial to quantify (and control) the changes in fiber networks under large physiologic strain levels. Specifically, we aim to understand the environment that the cells may encounter when either when subjected to in-vitro training in a bioreactor or in vivo post-implantation. In this study, we extended our previous studies of electrospun poly ester (urethane) urea scaffolds (ES-PEUUs) [1] to investigate the local deformations homogeneity and fiber tortuosity over ~50 μm x ~50 μm area on elastomeric ES-PEUU scaffolds under biaxial strain.

Materials and Methods

Electrospun scaffolds. The methods used to develop the PEUU scaffolds have previously been described [2]. The PEUU was synthesized and fed into a steel capillary and electrosprayed onto an aluminum mandrel, with a linear velocity of 1.5, 4.5 and 9.0 m/s.

Scaffold Characterization. To quantify fiber alignment, SEM images were obtained for the three groups (1.5 m/s, 4.5 m/s, and 9.0 m/s) and analyzed using custom image analysis software [1]. Tortuosity measures were performed on all unstrained scaffolds by tracking a fiber for the viewable length on the SEM image (Fig.1-a). Tortuosity was defined as fiber perimeter divided by the fiber end-to-end distance. Approximately 150 fibers were tracked for each spin speed. To quantify changes in tortuosity with strain, a stage was designed to allow the scaffold to be stretched and imaged using SEM (Fig 1-b).

SEM biaxial stage. A biaxial stretching device was developed to determine the effects of stretch on fiber tortuosity. Specific regions of the scaffolds were imaged in a nonstretched reference state and at strains up to 75%. Macro-level strains were determined by tracking markers placed on the scaffold defining a 3 mm x 3 mm region encompassing the imaged region.

Results/Discussion

The scaffolds were subjected to approximate equi-biaxial strain levels of ~75%. Tortuosity was higher in the direction of spin of the mandrel and varied most in scaffolds developed at higher mandrel velocities. Upon stretching the scaffolds, 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. Even with gradual strain, there was a considerable amount of reserve tortuosity in the fibers. It was not until ~30% strain that most of the fibers began to straighten. This phenomenon was observed in scaffolds for all three specimens.

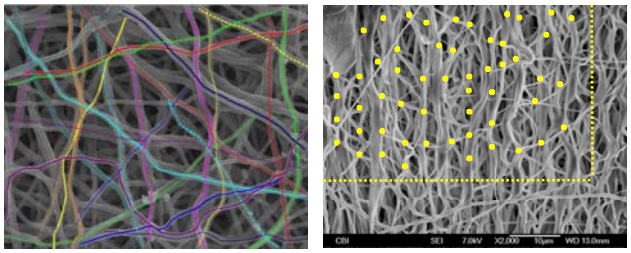

Figure 1 (a) Tracking of fibers to determine the degree of tortuosity with respect to angle, (b) Marker placing to allow for the analysis of strain

The ES-PEUU scaffolds displayed approximately the same orientation with increasing stretch, even with lessening tortuosity. This was expected since the scaffolds were stretched nearly biaxially and thus the overall angle of the fiber did not change. The strain fields for the three specimens also demonstrated variations across the region of interest; varying by as much as 15% (Fig. 2). The tortuosity and fiber splay results indicated that the micro-strain environment the cells would encounter would be affected most by a decrease in tortuosity.

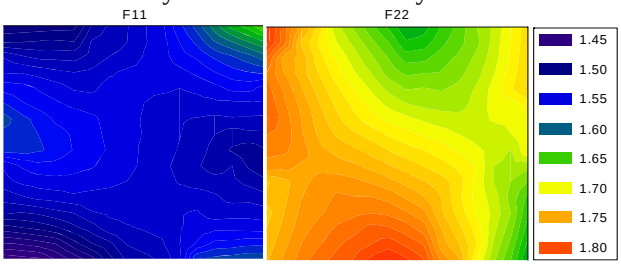

Figure 2 Stretch maps for the 1.5 m/s sample equi-biaxially strained to ~40%. (a) F_{11} = Preferred fiber direction stretch, (b) F_{22}=Cross-preferred fiber direction stretch. Both directions demonstrated strain variations of up to 15%, indicating that local deformations were heterogeneous at the 10-30 μm scale.

Conclusions

This work quantified the local changes in strain and fiber architecture that cells would witness when seeded. These changes could have implications in the resulting mechanobiological responses, and thus design of scaffolds for tissue engineering. Future work will investigate the effect of stretch on cells integrated into the scaffold and compare this with cellular deformation within the ECM.

References:[1] Courtney et al., Biomaterials, 27, 3631-38
[2] Stankus et al., Biomaterials. 2006; 27: 735-44

Acknowledgements: Funded by NIH grants HL-68816 and HL-69368