A MICRO-ARCHITECTURAL BASED STRUCTURAL MODEL FOR ELASTOMERIC ELECTROSPUN SCAFFOLDS FOR HEART VALVE TISSUE ENGINEERING

BACKGROUND. Improving how scaffold architectures affect cell morphology, metabolism, phenotypic expression, and predicting mechanical behaviors, are crucial goals in the development of engineered heart valve scaffolds. Studies are required to elucidate how the fibrous microstructure translates into specific tissue (or meso-scale) level mechanical behavior. Deterministic structural models can quantify how key structures contribute to the mechanical response as a function of bulk deformation across multiple scales, as well as provide a better understanding of cellular mechanical response to local micro-structural deformations. An appropriate representative volume element (RVE) size was determined by quantifying the point of stabilization of the architectural descriptors over image areas of increasing size. Computational material models were then generated and the macro mechanical response predicted via FEM simulations.

METHODS. Electrospun PEUU scaffold SEM images were analyzed using a combination of threshold segmentation followed by morphological procedures of eroding and dilating enabled the outer layer of fibers to be detected. A modified Delanauy network was generated from detected fiber intersections, with the complete procedure extracting: (1) fiber intersection spatial density, (2) connectivity, (3) fiber diameter, and (4) fiber angle distribution. Next, a random discrete distribution of points was generated on a 250 x 250 µm2 area following the real scaffold fiber characteristics obtained. A connectivity match between the real and simulated networks was achieved. A finite element model of the meso scale fiber network was constructed by importing the simulated network topology and with fibers modeled as linear elastic beam elements.

RESULTS. For the isotropic cases substantial regional variations were observed. In contrast, use of mechanically anisotropic scaffolds resulted in a more uniform principal strain distribution. Modulating the uniformity of the fiber preferred direction did not significantly impact the homogeneity qualities of the stress field. Moreover, the model was able to closely predict cellular deformations micro-integrated in the scaffold. Moreover, coupled Reaction-Diffusion models of tissue formation allowed prediction of synthesized tissue formation rates as a function of local cellular strain.

DISCUSSION. These results demonstrated that modulating the scaffold properties can play a major role in the mechanical response of the TEPV tissue stress. Tailoring the fabrication process, provides an effective method to introduce anisotropy into the scaffold material. These qualities can be controlled to provide a biomechanical response which more closely mimics the native tissue and therefore provide a physiologically relevant deformation state for the micro-integrated cell population, and thus guide tissue formation regimes