Determination of Mechanical Properties for 3D-Printed Microfibers

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Statement of Purpose: Tissue engineering scaffolds are currently being manufactured using advanced fabrication methods such as 3D printing to improve control over scaffold morphology[1]. For example, scaffolds can be 3D printed with well-defined micron-sized features, controllable porosity and pore architecture, and spatial organization of multiple materials with desired biochemistries to mimic native tissue architectures and properties. In the solvent-cast technique used here, inks were prepared by dissolving a biodegradable polymer in a volatile solvent. A customized 3D printer (Nordson EFD, Providence, RI) extrudes the ink into computer-defined patterns, and the solvent evaporates to leave behind a solid polymer fiber. This method is preferred over melt-based strategies to expand the library of printable polymer chemistries. However, this innovative process has not been extensively studied. There is a significant knowledge gap in characterizing how the processing parameters affect the mechanical properties of 3D-printed micro-fibers. The purpose of this work was to develop methods to characterize the morphology and tensile properties of solvent-cast 3D-printed poly(caprolactone) (PCL) fibers.

Methods: Solvent-cast 3D-printed fibers, approximately 130 and 260 μm in diameter, were produced by 3D printing 37% w/v PCL in hexafluoroisopropanol (HFIP) onto glass slides using 30 gauge (inner diameter 150 μm) and 27 gauge (inner diameter 200 μm) flat-tip needles. Since these fiber dimensions are too large for nano-mechanical testing and too small for individual testing, PCL fibers were printed in a parallel array of 25 fibers and tested as a group. Fiber arrays were fixed in paper frames to eliminate pre-stresses or misalignments. Once secured in diamond-faced mini-vice grips on a Zwick multiaxial materials testing machine (Zwick/Roell. Ulm, Germany), the paper frame was cut and fibers were extended uniaxially in tension at 25 mm/min until failure. The cross-sectional areas of the fibers were calculated using the mass and density of the extruded fibers. From the stress-strain curves, a linear fit to 2% strain was used to determine Young's modulus of elasticity.

Results: The Young's modulus of the solvent-cast 3D-printed PCL fibers showed a statistically-significant dependence on needle gauge. The 130 μm PCL fibers printed using the 30G needle resulted in a Young's modulus of 247.0 ± 26.6 MPa while the 260 μm PCL fibers printed with the 27 gauge needles resulted in a Young's modulus of 328.8 ± 7.4MPa. These values are comparable with literature values[2] of single electrospun fiber tensile tests. Variations in process parameters are shown between electrospinning and solvent casting as well as needle gauges.

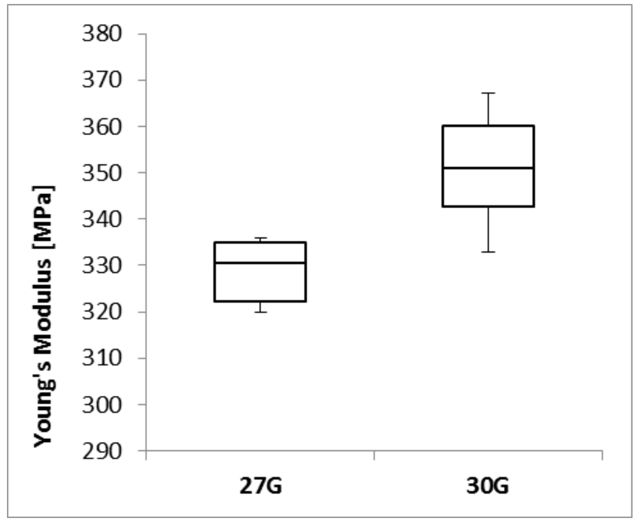

Figure 1. Young's modulus of PCL fibers 3D printed with two different needle gauges, 27G and 30G.

Conclusions: The tensile mechanical properties of solvent-cast 3D-printed PCL micro-fibers are influenced by the needle gauge, suggesting that the processing parameters affect PCL chain interactions within the fiber. Further studies are being conducted to characterize crystallinity of the printed fibers to correlate how needle gauge influences chain orientation during printing. Mechanical properties obtained from these experiments will enable the development of finite element analysis (FEA) models to rapidly evaluate a wide range of architectures.

References:

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