Engineering Three-Dimensional Biological Scaffolds Using a Modified Rotary Jet Spinning System

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Abstract:

Protein fibers with nanoscale diameters comprise the extracellular space in tissues and organs in the body. Current tissue engineering approaches often fail to recapitulate the three-dimensional nanoscale geometry of extracellular matrix fibers. Here, we have designed and developed modifications to a rotary jet spinning (RJS) system for fabricating nanofibers. Traditionally, the RJS produces two-dimensional sheets of polymer nanofibers at high speeds by solution extrusion through a perforated reservoir. Due to the nanometer thickness of the elongated polymer droplets, the nanofibers quickly dry and solidify and then are collected on a mandrel. The focus of this project is to engineer an automated nanofiber production and mandrel collection system in order to (a) easily create anisotropic scaffold tissue, and (b) generate small three-dimensional basic organ structures. The RJS system was constructed with multiple points of actuation for precise control, a computer program that allows for various parameter inputs to alter the fabrication process, a specially made support structure, and a custom designed interfacing circuit to allow for digital controls over high-voltage inputs and outputs. Currently, the RJS system is nearing the completion of its engineering process. With these modifications, we will be able to replicate the three-dimensional nanostructures of tissues and organs.

Introduction:

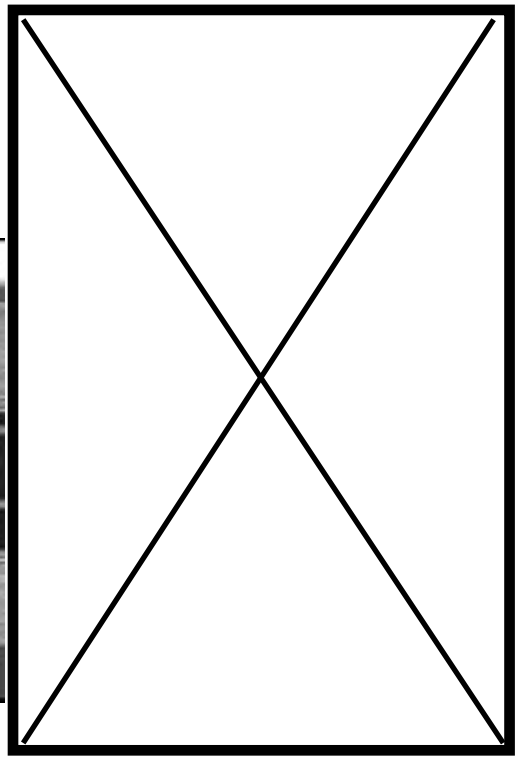
Advancements in biological research have created a demand for new substrates to be utilized for cellular development and testing. New biological scaffolds are needed to test cell dynamics in a three-dimensional environment and provide a structure for tissue development. This new structure would allow for more effective techniques in tissue experimentation *in vitro* [1]. It was hypothesized that the structure of these biological scaffolds could be engineered using the process of rotary jet spinning (RJS) [2]. This process can be visualized in Figure 1.

Figure 1: Rotary jet spinning (RJS) nanofiber extrusion.

Experimental Procedure:

The configured RJS system produced thin sheets of the scaffold nanofibers. The process needed to be changed to include a more accurately controlled environment and a nanofiber collection system to build three-dimensional biological scaffolding. The leading idea involved using a rotating mandrel collection system that could be motioned linearly through the developing thin sheets of nanofibers. This design allowed for varying speeds of collection and different scaffold structures. *Figure 2 has been removed from this report*.

This RJS system was designed to be run by computer program that interfaced with the motor controls of actuating part of



the system. In order to accurately design the interface, the respective motors needed to be chosen. For the center RJS motor that produces the nanofibers, an 80,000 rpm Nakanishi motor was selected to allow for a large range of centrifugal forces to aid in the development of smaller nanofibers. A Maxon motor was chosen for the collection mandrel. The Maxon motor can achieve speed rates up to 6,000 rpm, but it was reduced to 2,285 rpm to keep the collected nanofibers from being spun off of the mandrel.

Figure 3: RJS system program Graphical User Interface (GUI).

Figure 4: Center RJS system motor with mandrel.

The linearly actuating motor is used to move the collection mandrel through the nanofiber extrusion zone for collection. Different speeds of the linear motor cause the collection process to produce various scaffold structures. To allow for a wide range of scaffolding options, a high-speed/high-torque system was needed. For this task, a Misumi linear stepper motor actuator was chosen.

Results and Conclusions:

The program for the system was written in LabView with a simple Graphical User Interface (GUI) that displays the proper operation of the system to the end user as seen in Figure 3. To interface between the computer program and motor controls, a circuit was constructed to translate the digital signals of the computer into high-voltage signals and controls over the motors.

With the parts that were received, the RJS system center motor was constructed, as seen in Figure 4. When the center motor and the collection mandrel motor were connected to the main circuit board and tested, both worked in accordance to their respective operations in the program. These two were the only ones tested since the linear motor had still not been received.

Future Work:

The RJS system requires the integration of the linear motor system. After this is complete, the system can be tested operationally. The RJS system was designed with many variables in the system set to constant rates. This was done for simplicity in the engineering process. After the RJS system has been completely assembled and tested, an upgraded version has been devised that allows for the set variables to be varied both automatically through the operating program and manually. This will allow the system to fully test differing extrusion and collection scenarios to pinpoint optimum nanofiber extrusion techniques for building ideal anisotropic biological scaffolding for different solutions.

Acknowledgments:

I would like to thank my principal investigator, Prof. Kevin Kit Parker, for opening his lab and giving me the opportunity to learn. I'd also like to thank my mentor, Dr. Sung Jin Park, for his guidance and support. A special thanks is needed for Matthew Hemphill, Grant Gonzales, and Josue Goss for their help around the lab and great advice. I would like to thank Harvard University, the School of Engineering and Applied Science, the Disease Biophysics Group, Dr. Kathryn Hollar, Ms. Melanie-Claire Mallison, the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program, and the National Science Foundation (NSF) for the opportunity to receive this experience.

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