Design and Characterization of Porous Poly(Propylene Fumarate) Sleeve Scaffolds

Martha O. Wang[1], Charlotte E. Vorwald[1], Maureen L. Dreher[2], Eric J. Mott[3], David Dean[3], and John P. Fisher[1]
[1]Fischell Department of Bioengineering, University of Maryland, College Park, MD; [2]Division of Solid and Fluid Mechanics, Office of Science and Engineering Laboratories, Center for Devices and Radiological Health, Food and Drug Administration, Silver Spring, MD; [3]Department of Neurological Surgery, Case Western Reserve University, Cleveland, OH

Statement of Purpose: Scaffolds that are designed to include a space to house additional materials are referred to as carrier scaffolds. Carrier scaffolds have many advantageous properties in bone tissue engineering including mechanical support containing bioactive materials such as hydrogel encapsulated precultured stem cells. To take advantage of these benefits a porous, degradable polymer scaffold sleeve was designed using poly(propylene fumarate) (PPF), a well characterized polymer for bone tissue engineering[1,2]. This project investigated the techniques needed to model, fabricate, and evaluate controlled architecture (CA) carrier scaffolds with varying porosities and pore sizes. Random pore architecture (RPA) scaffolds are fabricated and mechanically characterized as a comparison to the CA scaffolds.

Materials, Methods and Analytical Procedures Used: PPF was synthesized as previously described[3]. RPA PPF scaffold sleeves were fabricated with 25% or 50% porosity and porogen sizes of 300-500μm or 710-850μm. The porosity of random pore scaffolds is calculated using the following equation: $\text{Theoretical Porosity} = \frac{\frac{C_s}{\rho_s}}{\frac{C_p}{\rho_p}+\frac{C_s}{\rho_s}} \times 100$ where C_p is the weight of PPF, ρ_p is the density of PPF C_s is the weight of salt and ρ_s is the density of NaCl. A photoinitiator solution, bis(2,4,6-trimethylbenzoyl) phenylphosphine oxide (Ciba Specialty Chemicals, Tarrytown, NY) in methylene chloride was mixed with the PPF and poured into glass vials. A rod was placed inside the glass vials to create a sleeve structure. The PPF constructs were photocrosslinked and porogen was leached as described previously[4]. Scaffolds were trimmed to reach the dimensional requirements for mechanical testing per ASTM standard D-695. Compressive properties were measured on an Instron mechanical testing system (33R/4465) at varying displacement rates of 0.5mm/min, 1.0mm/min and 10mm/min (n=2 per rate). CA scaffolds were fabricated using an envisionTEC (Ferndale, MI) Perfactory® device. Micro computed tomography (μCT) was performed using a SCANCO Medical (Brüttisellen, Switzerland) μCT 100 imaging system to nondestructively image and quantify scaffold parameters. Scaffolds were scanned and 3-D data sets were segmented using thresholds to separate pores and void spaces from polymer. Images were compiled and evaluated using Image Processing Language (IPL).

Results: PPF CA scaffolds can be fabricated with a variety of pore sizes and porosities. Four scaffolds with pore sizes of 400μm and 800μm pores and porosities of 25% and 50% were prepared. The four CA scaffold sleeve designs were composed of repeating units of rings (Figure 1a) connected by uniformly distributed cylindrical posts. These repeating units were stacked on top of each other to form a porous cylinder. The four designs were implemented in SolidWorks (Dassault Systèmes SolidWorks Corp., Waltham, MA) and then fabricated using an envisionTEC Perfactory® additive manufacturing device (Fig 1b – 1f). A 3-D rendering from μCT of the 25% porosity, 800 μm pores scaffold is shown below (Fig 1g). To compare mechanical properties and evaluate rate dependencies, RPA scaffolds were fabricated. The RPA scaffold mechanical compression testing found that the less porous scaffolds were stiffer than the porous scaffolds at all loading rates. The modulus of the 50% porosity group, 300 ± 69 MPa, was about half that of the 25% porosity group, 134 ± 17 MPa (Fig 2).

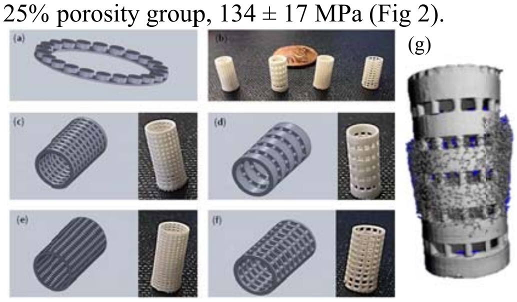

Figure 1: CA Scaffolds: SolidWorks models of CA scaffolds with their 3-D printed counterparts. (a) One repeating unit of a base ring and posts, (b) Photograph of fabricated scaffolds, (c) 25%, 400μm, (d) 25%, 800μm, (e) 50%, 400μm (f) 50%, 800μm, (g) μCT rendering of 25%, 800μm; foam is seen surrounding the scaffold to prevent movement during imaging.

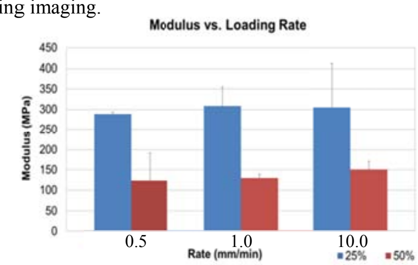

Figure 2: Modulus v. loading rate for 25% and 50% RPA scaffolds

Conclusion: PPF controlled architecture and random pore scaffolds can be fabricated and characterized with a variety of pore sizes and porosities. Mechanical testing of the random pore architecture scaffolds showed that the more porous scaffolds were less stiff and minimal rate dependencies were identified. Though the 25% porous RPA scaffolds showed the greatest moduli values the results are smaller than average trabecular elastic moduli (445MPa)[5]. Controlled architecture scaffolds may be modeled to evaluate the impact of pore size and porosity on mechanical properties. μCT may be used to non-destructively evaluate scaffold properties including effective porosity to compare to theoretical porosity.

References: **1)** Cooke, M.N., *J. Biomed. Matl. Res. B* (2002) 65-69., **2)** Fisher, J.P., *J. Biomed. Matl. Res.* (2002) 59 547-556. **3)** Kasper, F.K., *Nat. Protoc.* (2009) 4, 518-525; 2 **4)** Fisher, J.P., *Biomacromolecules, (2003)* 59 1335–1342. **5)** Karagergiou, V., Biomaterials, (2005) 26, 5474-5491