Development and Characterization of a Novel Polycaprolactone Fumarate (PCLF) Scaffold Manufactured through a Sacrificial Molding Technique

Steven Chase, Eric R. Wagner, Dalibel Bravo, Mahrokh Dadsetan, Sanjeev Kakar, Michael J. Yaszemski
Mayo Clinic, College of Medicine, Rochester MN

Statement of Purpose: An integral part of tissue engineering research is the design of new scaffolds and scaffold materials. Native tissues and natural and synthetic polymers have been suggested as suitable scaffold materials for tissue regeneration[1]. Polycaprolactone fumarate (PCLF) is a polymer based on the well-established polymer PCL with an added ability to crosslink using either chemical or UV crosslinking techniques. PCLF has an ultimate strength of 7 MPa and elastic modulus of about 130 MPa[2] suggesting its use in several applications. Different manufacturing techniques such as salt leaching, electrospinning, and 3D printing have been employed. Using sacrificial molding allows for the control of geometry of 3D printing while allowing for the use of many different polymers. This manufacturing technique may have applications in many different tissue engineering approaches where a consistent scaffold design is required.

Methods: PCLF was synthesized as previously described[2] using a two-step reaction process. Scaffolds were designed with large, interconnected pores to allow for high concentration cell loading and nutrient flow within the scaffold. Various pore geometries were designed to allow for different scaffold porosities and mechanical properties. Porous scaffold molds were designed using SolidWorks CAD software and printed using a SolidScape 3D printer. Printed molds (4mm by 6mm) were placed in glass tubes, and PCLF was injected over the sacrificial molds and crosslinked using UV light. Molds were removed using a mixture of methanol and acetone. Scaffolds were stored in methanol and transferred to 37°C water 12 hours before mechanical testing.

Three- dimensional micro-computed tomography (Micro-CT): The architecture of the scaffolds was measured using a compact cone-beam type tomography (Micro-CT, µCT 35, Scanco Medical). Scaffolds were placed in an cylindrical sample holder. For each scaffold the region of interest was selected following scout view and 500 slices with increments of 20µm were acquired covering one third the length of the scaffold. The porosities of the scaffolds were calculated using white-black thresholding.

Mechanical testing: Scaffolds were tested using a Bose ElectroForce testing machine. Scaffolds were subjected to either tensile or compressive loading to failure at a rate of 0.1667 mm/s. The load to failure, stiffness, ultimate load, and elastic modulus (normalized values were calculated to the total cross sectional area, i.e. 4mm by 6mm ideally) were calculated.

Results: Molds were designed in CAD software with various geometries. Initial designs incorporate a repeating 500 or 750 µm pore with equal spacing (**Figure 1**). This design produces a calculated porosity of 45% and 59% and a load absorbing cross sectional area of 3.75 and 3.375 mm^2, respectively. Using Hooke's law, the load to failure should be 26.3 and 23.6 N, respectively.

A representative micro-CT image is shown in Figure 2. Micro-CT provides a way to evaluate the internal structure of the scaffold. The CT calculated porosity is 71% and 81% for 500 and 750 µm pores. This is much higher than the

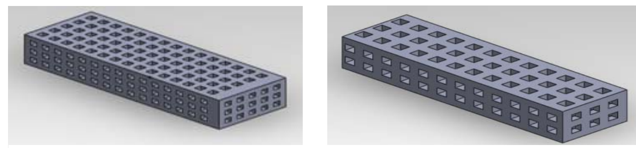

Figure 2: CAD design of the sacrificial mold. 500 µm on left and 750 µm on right

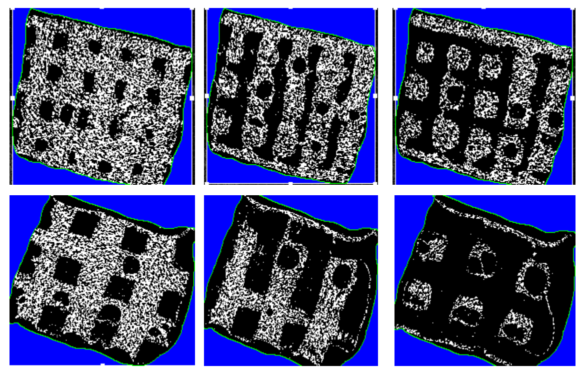

Figure 1: Representative micro-CT images of 500 µm (top) and 750 µm (bottom) pores.

	Load at Failure (N)	Ultimate strength (MPa)	Elastic modulus (MPa)
500 µm	19.5±4.2	1.24±0.25	16.25±4.20
750 µm	14.7±3.34	0.95±0.182	12.6±3.22

Table 1: Mechanical properties of scaffolds under tensile loading

theoretically calculated values from the CAD design. Air bubbles are seen inside the pillar structures result in an increase in porosity relative to the design.

The average load to failure, stiffness, ultimate strength, and elastic modulus of the 500 and 750 µm pore geometries are shown in Table 1. In both cases, the experimental load to failure of the scaffolds was less than predicted. Compression testing is in progress. This compares favorably with the 10-40N strength of repaired rabbit ACL[3] making it a good candidate for a ligament regeneration model.

Conclusions: Sacrificial molding using 3D printed molds provides a rapid method to produce a polymer scaffold with desired geometry. Additional geometries can be developed to provide the desired mechanical properties. This manufacturing technique may have application for many tissue engineering applications such as ligament, tendon, and cartilage regeneration.

Reference: 1. Nair L, et al. *Prog Polym Sci,* 32: 762-98, 2007. 2. Runge B, et al. *Acta biomaterialia,* 8(1): 133-43, 2012. 3. Soon M, et al. *Am J Sports Med,* 45(6): 2007

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