Contraction of 3D Designed Polycaprolactone Scaffolds During Post-Processing

Jessica M. Kemppainen, Kristen L Wolff, Annie G. Mitsak, Scott J. Hollister
Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI

Statement of Purpose: Polycaprolactone (PCL), an FDA approved, biodegradable, nontoxic polymer has gained popularity in the field of tissue engineering over the past decade. PCL's slow degradation properties coupled with it's mechanical properties make it ideal for drug delivery and bone reconstruction, where is has commonly been applied. More recently, this material is being exploited in a wider range of applications such as spinal cord regeneration[1], cartilage repair[2], brain tissue regeneration[3], or bladder reconstruction[4]. Commercially available PCL is being fabricated in a variety of ways for these applications. Here, we focus on 3D designed PCL scaffolds made via melt casting of 37kDa or 50kDa material into wax molds.

It is of significant importance to fully characterize the structural properties of 3D designed scaffolds before carrying any fabrication process into clinical applications. When designing custom scaffolds modeled from images of specific patient MRI or CT data or when designing custom architectural features, it will be important to compensate for any material changes that occur during post-processing or even implantation. Here we characterize the contraction of melt-cast PCL caused by post-processing of the scaffolds in ethanol.

Methods: Scaffold Fabrication-3D-scaffolds (3mm height, 6.35mm diameter, 1mm spherical pores) were designed using custom Interactive Data Language™ programs (IDL; Research Systems, Inc., Boulder, CO). Inverse wax molds of designs were processed on a Solidscape 3D printer (SolidScape Inc., Merrimack, NH). Scaffolds were made by pressing the wax molds directly into melted 37kDa (CAPA 6400, Solvay Caprolactones, Warrington, Cheshire, UK) or 50kDa (Polysciences, Warrington, PA). Briefly, PCL pellets (37kDa) or powder (50kDa) were packed into a Teflon mold, and melted (115°C, 1 Torr, 120 minutes). After melting and air bubble removal, the Teflon mold was pulled from the oven, and allowed to cool for 270 seconds at room temperature until they reached 80°C (just below the melting temperature of the wax molds). At this time, inverse wax molds were pressed into the melted PCL, and the entire construct was cooled overnight. The wax was then dissolved from the PCL using 100% EtOH.

Micro-Computed Tomography Analysis-Fabricated scaffolds were scanned dry using a MS-130 high resolution micro-computed tomography (µCT) scanner (GE Medical Systems, Toronto, CAN) at 16 mm voxel resolution, 75kV and 75mA. 3D designed scaffolds (n=5 per design for 37kDa, n=4 per design for 50kDa) were scanned at two phases throughout processing: after wax mold has been cast into PCL material and after removal of
wax mold during a 30h EtOH soak. Changes in outer diameter were assessed.

Results: Processing in ethanol causes PCL scaffolds to contract significantly. Figure 1 illustrates representative uCT images of a scaffold before and after EtOH soaking. Measurements of changes in scaffold outer diameter for each molecular weight are seen in Table 1.

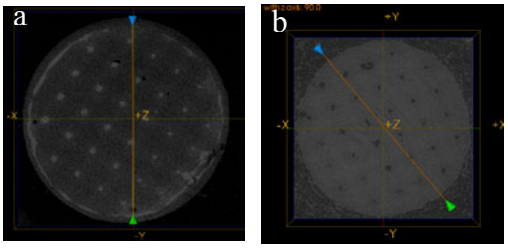

Figure 1. µCT images depicting representative images of a scaffold before (a) and after (b) ethanol soaking. The distance between green and blue arrows measures 6.65mm in both images, displaying the contraction in (b).

Table 1. Contraction of PCL as measured by change in outer diameter of scaffolds.

	37 kDa PCL (n=5)			50 kDa PCL (n=4)		
Scaffold Design (porosity)	**Start dia. (mm)**	**Δ Outer dia. (mm)**	**Δ Outer dia. (%)**	**Start dia. (mm)**	**Δ Outer dia (mm)**	**Δ Outer dia. (%)**
54%	6.782 ± .03	.422 ± .05	6.222 ± .70	6.735 ± .02	.418 ± 0.11	6.196 ± 1.62
63%	6.754 ± .06	.466 ± .08	6.910 ± 1.16	6.713 ± .04	.463 ± 0.08	6.884 ± 1.09
70%	6.722 ± .07	.404 ± .05	6.01 ± .77	6.620 ± .07	.405 ± 0.11	6.108 ± 1.67
	Overall Average Change (%)					
	6.753 ± .06	.431 ± .06	6.38 ± 0.96	6.689 ± .07	.428 ± 0.10	6.40 ± 1.45

Conclusions: Ethanol is often used for processing of scaffolds, as shown here to dissolve wax, or in many instances to sterilize implants. Here, we find that EtOH causes significant contraction of PCL, due to molecular compaction of the carbon chain or a change in bond structure when placed in a polar solution.

Therefore, when designing custom scaffolds as mentioned earlier, it will be important to compensate for contraction of material seen in this study. Computational up scaling of the scaffold implant could be applied to fix this change, or a less polar solvent, that does not cause contraction, can be investigated for removal of wax. Compensating for the contraction of PCL is also important in situations where the material will be placed in a polar in vivo environment. For instance, Yu et al[4] document contraction of PCL in bladder applications, where the material is in contact with urine.

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