Morphological Evaluation of Superporous Poly(vinyl alcohol) Cryogels

Samuel J. Laurencin,[1] Suzanne Maher,[2] and Anthony M. Lowman[1]
[1]Department of Chemical and Biological Engineering, Drexel University, Philadelphia, PA, USA
[2]Hospital for Special Surgery, New York, NY, USA

Statement of Purpose: Osteoarthritis is a debilitating condition manifested as focal defects within cartilage at varying depths from the articular surface to the subchondral bone. We propose a novel defect-filling scaffold using a physically crosslinked, poly(vinyl alcohol) cryogel with a superporous internal network generated through the controlled removal of an organic solvent phase. Current engineered scaffolds present limitations in providing adequate porosity for cellular infusion and implant integration while maintaining mechanical integrity for load-baring-tissue repair (Karande TS. Ann Biomed Eng. 2004;32:1728-43). Current research aims to characterize synthesis parameters on cryogel porosity and compressive modulus and overcome any design restrictions through post-synthesis optimization to achieve the targeted biomechanical properties. We hypothesize that the scaffold will restore load bearing abilities at the defect site for knee articular cartilage and provide an environment for chondrocyte migration into, and proliferation within, the cryogel.

Methods: A 10wt% aqueous solution of PVA was mixed with Dicloromethane (DCM) or Ethyl Acetate (EA) in solution concentrations ranging from 0 to 25vol%. The emulsion underwent successive freezing/thawing cycles (21hr/3hr) to form a physically crosslinked cryogel. The impact of solvent concentration, mixing method (stirred or homogenized), and mixing speed (300rpm to 2000rpm) was assessed for a mixing duration of 10min. PVA solubility limitations prompted an optimization approach in controlling water removal to improve mechanical strength. Cryogels were either exposed to standard ambient temperature and humidity during each thawing period throughout the synthesis or rehydrated by lyophilizing for 48hrs following synthesis then suspended in H_20 for 48hrs to obtain an equilibrium degree of swelling. Unconfined compression tests were used to evaluate cryogel compressive modulus. Environmental Scanning Electron Microscographs (ESEM) provided qualitative assessment of cryogel porosity.

Results: DCM caused a slight decrease in compressive modulus from the control modulus, which contained no organic solvent. The modulus did not vary significantly with changes in DCM concentration. EA significantly increased the modulus proportionally with solvent concentration. Homogenous emulsions were difficult to obtain with high solvent concentrations of 25vol%. The viscous nature of PVA prohibited stirring above 300rpm and minimal changes in modulus was shown with different stirring speeds. Homogenizing the solutions provided a wider range of attainable modulus values and showed a proportional relationship with speed and modulus. Stirring and homogenizing both yielded modulus values below the target value. Figure 1 shows the modulus values at 30% strain for various mixing conditions and both optimization techniques using DCM. The target modulus was reached by homogenizing the solution at high speed and rehydrating the cryogel. Rehydrated cryogels were reswellable to 70% of the original water concentration, keeping in line with the water content of articular artilage.

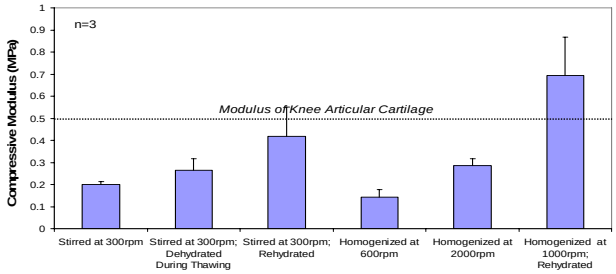

Figure 1: Compressive modulus at 30% strain

Figure 2 shows PVA with 10vol% DCM stirred at 300rpm before (A) and after (B) lyophilizing. The porous structure with mean pore diameter of 30μm remains intact throughout the freeze-drying optimization process.

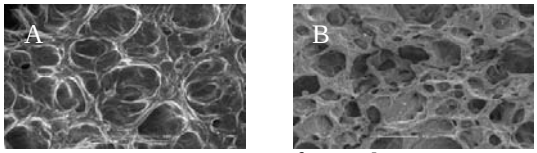

Figure 2: ESEM of stirred PVA

Figure 3 shows the porosity at low magnification (A) and high magnification (B) resulting from homogenizing PVA with 10vol% DCM at 600rpm. Increasing the speed of homogenizing decreased the level of porosity. EA provided a more uniform pore diameter and increased the porosity more than DCM at the same concentration.

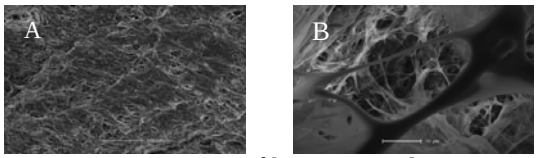

Figure 3: ESEM of homogenized PVA

Conclusions: Homogenizing PVA with organic solvent at 10vol% yields a superporous cryogel with variable porosity. Rehydrating cryogels greatly improves the compressive modulus. Using EA shows improved modulus and a more uniform pore network than DCM. This study shows the suitability of PVA with superporosity fabricated through organic solvent phase separation to be a novel material for articular cartilage repair. Future studies aim to quantify pore volume and assess cellular migration into cryogel *in vitro.*