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Fabrication of poly-$_{DL}$-lactide/polyethylene glycol scaffolds using the gas foaming technique

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ABSTRACT

The aim of this study was to prepare poly-$_{DL}$-lactide/polyethylene glycol (P_{DL}LA/PEG) blends to improve medium absorption and cell proliferation in the three-dimensional (3-D) structure of their scaffolds. Carbon dioxide (CO_2) was used as a foaming agent to create porosity in these blends. The results of Fourier transform infrared (FTIR) spectroscopy demonstrated that the blends were homogeneous mixtures of P_{DL}LA and PEG. The peak shifts at 1092 and 1744 cm^{-1} confirmed the presence of molecular interactions between these two compounds. Increasing the PEG weight ratio enhanced the relative crystallinity and hydrophilicity. The P_{DL}LA/PEG blends (especially 80/20 and 70/30 weight ratios) exhibited linear degradation profiles over an incubation time of 8 weeks. The mechanical properties of P_{DL}LA/PEG blends having less than 30 wt.% PEG were suitable for the fabrication of porous scaffolds. Increasing the concentration of PEG to above 50% resulted in blends that were brittle and had low mechanical integrity. Highly porous scaffolds with controllable pore size were produced for 30 wt.% PEG samples using the gas foaming technique at temperatures between 25 and 55 °C and pressures between 60 and 160 bar. The average pore diameters achieved by gas foaming process were between 15 and 150 μm, and had an average porosity of 84%. The medium uptake and degradation rate of fabricated P_{DL}LA/PEG scaffolds were increased compared with neat P_{DL}LA film due to the presence of PEG and porosity. The porous scaffolds also demonstrated a lower modulus of elasticity and a higher elongation at break compared to the non-porous film. The fabricated P_{DL}LA/PEG scaffolds have high potential for various tissue-engineering applications.

1. Introduction

Poly-$_{DL}$-lactide (P_{DL}LA) has been widely used for the fabrication of three-dimensional (3-D) scaffolds due to its superior mechanical properties, biocompatibility and biodegradability [1–3]. However, the hydrophobicity of P_{DL}LA results in poor medium uptake and subsequently limited cellular activities [1]. The hydrophobic surface also leads to protein adsorption from the blood when the scaffold is used in vivo, which causes side effects [2]. Blending P_{DL}LA with a polymer such as poly(ethylene glycol) (PEG) may enhance its hydrophilic properties [1,3–10]. P_{DL}LA/PEG blends acquire properties that cannot be found in individual polymers [11,12].

Copolymerization has been used to prepare various P_{DL}LA/PEG blends; the copolymer properties are functions of their compositions and the molecular weights of each monomer [5,13]. Saito et al. [5] produced P_{DL}LA/PEG copolymers for the delivery of bone morphogenetic proteins and the induction of bone formation. The copolymers exhibited a desirable balance between degradation rate and hydrophilicity, and induced the ectopic formation of new bone when evaluated in vivo [5]. An alternative approach is to prepare physical mixtures of these polymers by solvent casting using a solvent that dissolves both polymers [1,9] or emulsion/solvent evaporation using two immiscible solvents, such as water and dichloromethane (DCM) [4].

Porous scaffolds are produced using techniques such as electrospinning [9,14] and freeze drying [1] based on homogeneous blends of two components. Cui et al. [9] used electrospining and prepared a film by processing a mixture of P_{DL}LA and PEG (0–50 wt.% PEG) in acetone/DCM (3/1 by vol.). A homogeneous mixture with pore sizes between 5 and 10 μm was fabricated by this method. The two-dimensional structure of this scaffold and the small pore sizes created by this method were hurdles for applications such as cell proliferation in 3-D structure [9]. Maquet et al. [1] improved the hydrophilicity of P_{DL}LA foams by adding amphiphilic block copolymers of lactide and ethylene oxide (PELA). The porous P_{DL}LA/PELA foams were prepared by freeze drying the solutions in dioxane and chloroform. It was found that the degradation and wettability of the resultant foams were significantly increased when a PELA concentration of 10 wt.% was used. The fabricated blend foams using a 10 wt.% PELA contained both micropores (10 μm) and macropores (100 μm) [1]. The P_{DL}LA/PELA foams

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